AN OPTIMUM MULTISENSOR APPROACH FOR DETAILED ENGINEERING SOILS MAPPING

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by

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PURDUE UNIVERSITY
LAFAYETTE INDIANA

CHAPTER 4

METHODS OF INVESTIGATION

Introduction

Information on soils is not directly observable on the photography or imagery. It is interpreted by deduction and inference based on the evaluation of the pattern elements of form, and tone and texture. Therefore, the optimum system would be the one with the maximum potential for evaluating the pattern elements. To determine the optimum system, various types of aerial photography and imagery were obtained over selected test sites during a one year period.

The initial test flights were utilized to finalize the study sites and to plan the subsequent multisensor flight coverages. In conjunction with the aerial flights, field measurements were made in an attempt to evaluate some of the pertinent parameters affecting the aerial photography and imagery. The amount and type of field measurements performed were limited during the initial flights. The attempts at that stage were to choose the final areas for detailed study and to determine the type of information that should be recorded during aerial flights. During the final flights extensive field measurements were performed. Included in the data collection were: (1) surface soil moisture contents; (2) ground photographs taken with various film types and with

a nine-lens camera[1]; and (3) field radiometer readings in the 8 to 14 micron band. In addition, available meteorological data collected at local weather stations[2] were obtained for use in the analysis of the data.

The attempt to arrive at an optimum multisensor system for performing detailed engineering soils analyses was largely based on a qualitative approach. This approach consisted of the interpretation, comparison and evaluation of all the photography and imagery obtained. Quantitative measurements such as field moisture determinations, field radiometer measurements and densitometric measurements of the photography and imagery were utilized wherever possible to assist in the qualitative evaluation.

A quantitative approach also was evaluated as part of this study. In the quantitative approach, densitometric scans were performed over various land forms in an attempt to determine whether typical patterns existed for the various land forms studied and to determine what parameters affected the patterns obtained. Limited investigations were also made to determine what parameters should be measured and to what degree they could be used to evaluate or distinguish between different engineering soils. In addition, a rapid technique was developed utilizing the densitometers to determine the colors present on color photography and to classify it according to the Munsell color system.

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1 The nine-lens camera used on this project was on loan from the Infrared and Optical Sensor Laboratory, Institute of Science and Technology, University of Michigan, the designers of the camera.

2 Local weather data were obtained from the Purdue Agronomy Farm located at the northern part of Site II and from the Purdue Airport located east of Site I. (Site locations described in next section.)

Test Sites

Three test sites were selected for this study. These are shown in Figure 33. Sites I and II are less than five miles from Purdue University in Lafayette, Indiana and Site III is about fifteen miles away. These sites were chosen for several reasons. First, to obtain coverage by various classified sensors. To accomplish this, a cooperative arrangement was made with the research group in the Botany and Plant Pathology Department of Purdue University[3]. This group had been obtaining multisensor coverage in their research project. Test sites were chosen adjacent to or in the vicinity of those utilized by this group and joint flight programs were planned. Second, these sites contained the greatest variety of land forms and engineering soils present within the limited area of choice. Third, they were convenient to Purdue University and its airport so that the aerial coverage and field measurements could be coordinated during flight programs. Finally, for two of the three sites, extensive literature and drilling information was available to assist in the analysis of the data.

The selection of test sites with extensive background information on surface soils and subsurface conditions was an important consideration. Having this detailed information available decreased the time and cost needed for field explorations and investigation. It also enabled detailed comparisons to be made between the various sensors and film types and to ascertain whether certain patterns obtained on the photography and imagery could be related directly to soil types and whether

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[3] This group now performing research under the organization entitled "Laboratory for Agricultural Remote Sensing (LARS)" located at the Purdue University McClure Research Park.

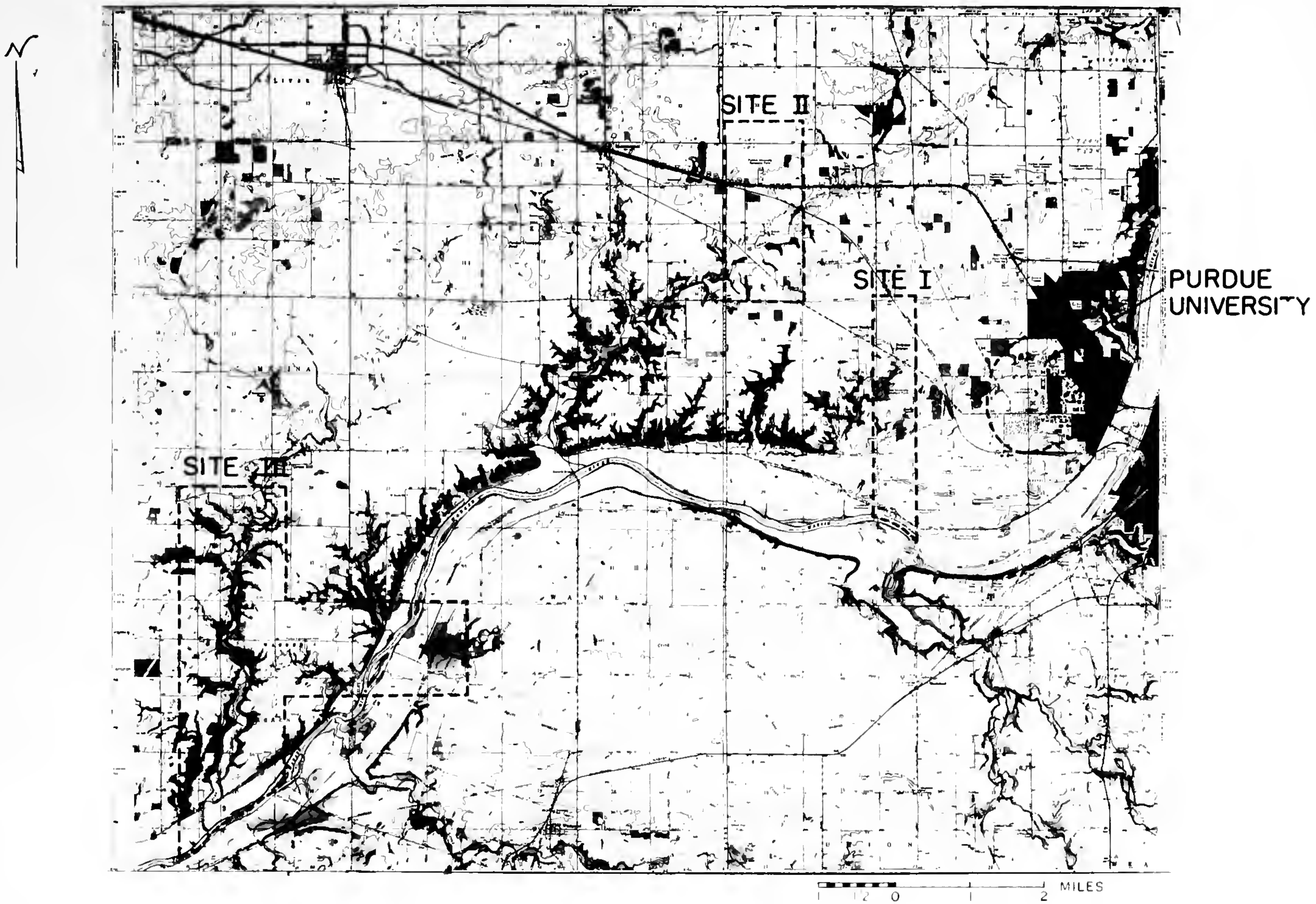


FIGURE 33. LOCATION OF TEST SITES.

these patterns reflected surface or subsurface conditions.

The types of information available included well logs, borings, weather data, and an engineering soils map and agricultural soils survey map for Tippecanoe County. Pertinent well logs and borings and their location are included in Appendix A. A portion of the Engineering Soils Map for Tippecanoe County which covers Sites I, II and a portion of III is presented in Figure 34. This map indicates the various land forms, parent materials and soil textures present in the area. Figure 35 includes a portion of the Agricultural Soil Survey Map for Tippecanoe County covering the test sites located in the county. This map gives detailed information on the soil textures and drainage conditions found in the upper three to six feet of the soil units mapped. The soil units shown are those mapped by soil scientists. To correlate these units to engineering soil units, reference has to be made to the accompanying text in the soil report.

Flight Program

Since the flight program for the coverage of the test sites was developed jointly with the research group in the Botany and Plant Pathology Department of Purdue University (now LARS), compromises on dates of coverage and, at times, on the amount of coverage were necessary. Table 5 lists the flight coverage obtained for the project study.

The initial flight in May of 1965 was to obtain coverage over several areas of interest in order to study the types of soils exposed and to choose the final test sites for the project study. The next three flights (7/1, 7/26 and 9/1, 1965) were flown primarily for the LARS group to obtain information on vegetation. The data from these

LEGEND

PARENT MATERIALS
(GROUPED ACCORDING TO LAND FORM AND ORIGIN)

RIOGE MORAINE

GROUND MORAINE

OUTWASH PLAIN

ALLUVIAL PLAIN

THIN LOESS

PEAT ANO MUCK

SAND DUNE

TERRACE

LACUSTRINE PLAIN

ESKER

KAME

INTERBEDDED SANDSTONE AND SHALE

MORAINES ON BEDROCK

MISCELLANEOUS

GRAVEL PIT

LAKE AND POND

BOULDER BELT

CLAY OEPRESSION

HIGHLY ORGANIC TOPSOIL

SOIL SAMPLING SITE

TEXTURAL SYMBOLS
(SUPERIMPOSED ON PARENT MATERIAL SYMBOLS TO SHOW RELATIVE COMPOSITION)

SAND

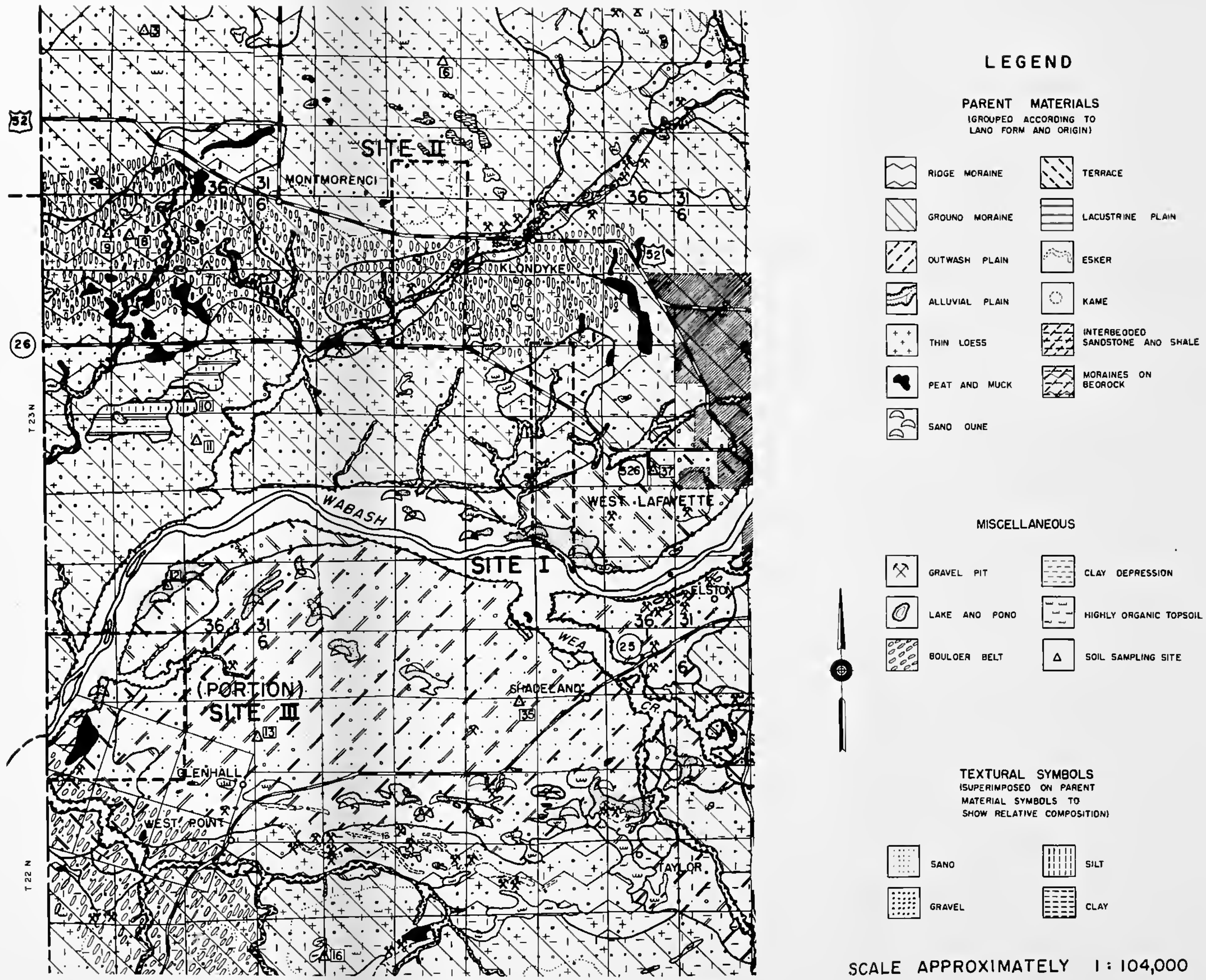
GRAVEL

SILT

CLAY

SCALE APPROXIMATELY 1 : 104,000

ILS MAP.



After YEH (192)

FIGURE 34. PORTION OF TIPPECANOE COUNTY ENGINEERING SOILS MAP.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

TIPPECANOE COUNTY, INDIANA

PURDUE UNIVERSITY AGRICULTURAL EXPERIMENT STATION

SOILS LEGEND

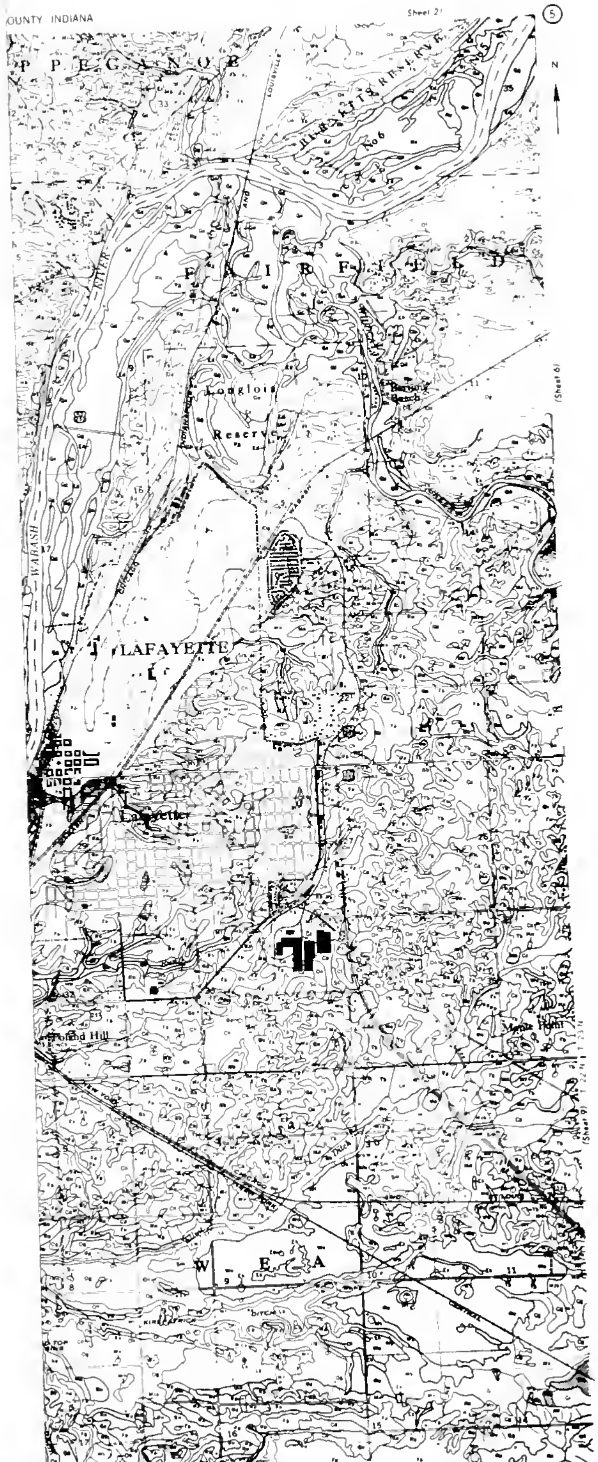
SOIL SYMBOL	SOIL NAME
Aa	Abington silty clay loam, 0-3 percent slopes
Ba	Brookston silt loam, 0-3 percent slopes
Bb	Brookston silty clay loam, 0-3 percent slopes
Ca	Carlisle muck
Cb	Chalmers silt loam, 0-3 percent slopes
Cc	Chalmers silty clay loam, 0-3 percent slopes
Cd	Cope silt loam, 0-3 percent slopes
Ce	Cope silty clay loam, 0-3 percent slopes
Cf	Corwin silt loam, 0-2 percent slopes
Cg	Crane silt loam, 0-3 percent slopes
Ch	Crosby silt loam, 0-3 percent slopes
Ci	Crosby silt loam, 3-5 percent slopes, eroded
Da	Dana silt loam, 0-2 percent slopes
Db	Delmar silt loam, 0-3 percent slopes
Ea	Edwards muck
Eb	Eel loam, 0-3 percent slopes
Ec	Eel silt loam, 0-3 percent slopes
Ed	Eel silty clay loam, 0-3 percent slopes
Ee	Elston fine sandy loam, 0-3 percent slopes
Ef	Elston fine sandy loam, 3-8 percent slopes
Eg	Elston loam, 0-3 percent slopes
Eh	Elston loam, 3-8 percent slopes
Ei	Elston loam, 3-8 percent slopes, eroded
Ej	Elston loam, 8-15 percent slopes, eroded
Ek	Elston silt loam, silted, 0-3 percent slopes
Fa	Fincastle silt loam, 0-3 percent slopes
Fb	Fox loam, 0-3 percent slopes
Fc	Fox loam, 3-8 percent slopes
Fd	Fox loam, 3-8 percent slopes, eroded
Fe	Fox loam, 3-8 percent slopes, eroded kame phase
Ff	Fox loam, 8-12 percent slopes
Fg	Fox loam, 8-12 percent slopes, eroded
Fh	Fox loam, 8-12 percent slopes, kame phase
Fi	Fox loam, 8-12 percent slopes, eroded kame phase
Fj	Fox loam, 12-25 percent slopes
Fk	Fox loam, 12-25 percent slopes, eroded
Fl	Fox loam, 12-25 percent slopes, kame phase
Fm	Fox loam, 12-25 percent slopes, eroded kame phase
Fn	Fox loam and clay loam, 8-12 percent slopes, severely eroded
Fo	Fox loam and silt loam, 3-8 percent slopes, kame phases
Fp	Fox silt loam, 0-3 percent slopes
Fq	Fox silt loam, 3-8 percent slopes
Ga	Genesee fine sandy loam, 0-4 percent slopes
Gb	Genesee fine sandy loam, high bottom, 0-3 percent slopes
Gc	Genesee loam, 0-4 percent slopes
Gd	Genesee loam, high bottom, 0-3 percent slopes
Ge	Genesee silt loam, 0-4 percent slopes
Gf	Genesee silt loam, high bottom, 0-4 percent slopes
Gg	Genesee silty clay loam, 0-4 percent slopes
Gh	Genesee silty clay loam, high bottom, 0-3 percent slopes
Gi	Glenhall silt loam, 0-3 percent slopes
Ha	Hagener loamy fine sand, 2-12 percent slopes
Hb	Hennepin loam, 25-50 percent slopes
Hc	High Gap silt loam, 1-8 percent slopes
Hd	Homer silt loam, 0-3 percent slopes
Ka	Kaskaskia loam, 0-3 percent slopes
Kb	Kaskaskia silt loam, 0-3 percent slopes
Kc	Kokomo silty clay loam, 0-3 percent slopes
La	Linwood muck
Lb	Longlois loam, 0-3 percent slopes
Lc	Longlois loam, 3-8 percent slopes
Ld	Longlois loam, 3-8 percent slopes, eroded
Le	Longlois silt loam, 0-3 percent slopes
Lf	Longlois silt loam, 3-8 percent slopes
Lg	Longlois silt loam, 3-8 percent slopes, eroded
Ma	Made land
Mb	Martinsville loam, 0-5 percent slopes
Mc	Martinsville silt loam, 0-5 percent slopes
Md	Mellott silt loam, 0-3 percent slopes
Me	Mellott silt loam, 3-8 percent slopes
Mf	Mellott silt loam, 3-8 percent slopes, eroded
Mg	Mellott silt loam, 8-12 percent slopes
Mh	Mellott silt loam, 8-12 percent slopes, eroded
Mi	Mellott silt loam and silty clay loam, 3-8 percent slopes, severely eroded
Mj	Mellott silt loam and silty clay loam, 8-12 percent slopes, severely eroded
Mk	Miami loam, 3-8 percent slopes
Ml	Miami loam, 3-8 percent slopes, eroded
Mm	Miami loam, 8-12 percent slopes
Mn	Miami loam, 8-12 percent slopes, eroded
Mo	Miami loam, 12-25 percent slopes
Mp	Miami loam, 12-25 percent slopes, eroded
Mq	Miami silt loam, 0-3 percent slopes
Mr	Miami silt loam, 3-8 percent slopes
Ms	Miami silt loam, 3-8 percent slopes, eroded
Mt	Miami silt loam, 8-12 percent slopes
Mu	Miami silt loam, 8-12 percent slopes, eroded
Mv	Miami silt loam, 12-25 percent slopes
Mw	Miami silt loam, 12-25 percent slopes, eroded
Mx	Miami silt loam and silty clay loam, 8-12 percent slopes, severely eroded
My	Millsdale silty clay loam, 0-3 percent slopes
Mz	Milton silt loam, 2-8 percent slopes
Mza	Monitor silt loam, 0-3 percent slopes
Mzb	Montmorenci silt loam, 0-3 percent slopes
Mzc	Muskingum stony silt loam, 10-30 percent slopes
Na	Nineveh loam, 0-3 percent slopes
Oa	Oaktown loamy fine sand, 3-8 percent slopes
Ob	Oaktown loamy fine sand, 8-12 percent slopes
Oc	Oaktown loamy fine sand, 12-25 percent slopes
Od	Ockley loam, 0-3 percent slopes
Oe	Ockley loam, 3-8 percent slopes
Of	Ockley loam, 3-8 percent slopes, eroded
Og	Ockley silt loam, 0-3 percent slopes
Oh	Ockley silt loam, 3-8 percent slopes
Oi	Ockley silt loam, 3-8 percent slopes, eroded
Ok	Octagon silt loam, 3-8 percent slopes
Ol	Octagon silt loam, 3-8 percent slopes, eroded
Om	Odell silt loam, 0-2 percent slopes
On	Otterbein silt loam, 0-3 percent slopes
Pa	Parr loam, 2-5 percent slopes
Pb	Parr loam, 2-10 percent slopes, eroded
Pc	Parr silt loam, 0-2 percent slopes
Pd	Parr silt loam, 2-5 percent slopes
Pe	Parr silt loam, 2-5 percent slopes, eroded
Pf	Parr silt loam, 5-8 percent slopes, eroded
Pg	Parr silt loam, 8-12 percent slopes, eroded
Ph	Parr silt loam and silty clay loam, 8-12 percent slopes, severely eroded
Pi	Pettit silt loam, 0-3 percent slopes
Ra	Randolph silt loam, 0-3 percent slopes
Rb	Raub silt loam, 0-2 percent slopes
Rc	Riverwash
Rd	Rodman gravelly loam, 25-35 percent slopes
Re	Romney silty clay loam, 0-2 percent slopes
Rf	Ross loam, 0-3 percent slopes
Rg	Ross silt loam, 0-3 percent slopes
Rh	Ross silty clay loam, 0-3 percent slopes
Ri	Russell loam, 3-8 percent slopes
Rj	Russell loam, 3-8 percent slopes, eroded
Rk	Russell loam, 8-12 percent slopes, eroded
Rl	Russell loam, 12-25 percent slopes, eroded
Rla	Russell loam and clay loam, 8-12 percent slopes, severely eroded
Rm	Russell loam and silty clay loam, 8-12 percent slopes, severely eroded
Rn	Russell silt loam, 0-3 percent slopes
Ro	Russell silt loam, 3-8 percent slopes
Rp	Russell silt loam, 3-8 percent slopes, eroded
Rq	Russell silt loam, 8-12 percent slopes
Rr	Russell silt loam, 8-12 percent slopes, eroded
Rs	Russell silt loam, 12-25 percent slopes
Rt	Russell silt loam, 12-25 percent slopes, eroded
Ru	Russell silt loam and silty clay loam, 3-8 percent slopes, severely eroded
Rv	Russell silt loam and silty clay loam, 8-12 percent slopes, severely eroded
Rw	Russell silt loam and silty clay loam, 12-25 percent slopes, severely eroded
Sa	Shadeland silt loam, 0-2 percent slopes
Sb	Shoals silt loam, 0-3 percent slopes
Sc	Sidell silt loam, 0-2 percent slopes
Sd	Sidell silt loam, 2-5 percent slopes
Se	Sidell silt loam, 2-5 percent slopes, eroded
Sf	Sidell silt loam, 5-8 percent slopes
Sg	Sidell silt loam, 5-8 percent slopes, eroded
Sh	Sidell silt loam, 8-12 percent slopes
Si	Sidell silt loam, 8-12 percent slopes, eroded
Sj	Sidell silt loam and silty clay loam, 2-5 percent slopes, severely eroded
Sk	Sidell silt loam and silty clay loam, 5-8 percent slopes, severely eroded
Sl	Sidell silt loam and silty clay loam, 8-12 percent slopes, severely eroded
Sm	Sleeth silt loam, 0-3 percent slopes
Sn	Sloan silt loam, 0-3 percent slopes
So	Sloan silty clay loam, 0-3 percent slopes
Ta	Tippecanoe silt loam, 0-3 percent slopes
Tb	Toronto silt loam, 0-3 percent slopes
Wa	Warsaw loam, 0-3 percent slopes
Wb	Warsaw loam, 3-8 percent slopes
Wc	Warsaw loam, 3-8 percent slopes, eroded
Wd	Warsaw loam, 3-8 percent slopes, kame phase
We	Warsaw loam, 3-8 percent slopes, eroded kame phase
Wf	Warsaw loam, 8-20 percent slopes, eroded
Wg	Warsaw loam, 8-12 percent slopes, kame phase
Wh	Warsaw loam, 8-12 percent slopes, eroded kame phase
Wi	Warsaw loam, 12-25 percent slopes, eroded kame phase
Wj	Warsaw silt loam, 0-3 percent slopes
Wk	Warsaw silt loam, 3-8 percent slopes
Wl	Warsaw silt loam, 3-8 percent slopes, eroded kame phase
Wm	Warsaw silt loam, 8-12 percent slopes, eroded kame phase
Wn	Washtenaw silt loam, 0-3 percent slopes
Wo	Wea silt loam, 0-3 percent slopes
Wp	Wea silt loam, 3-8 percent slopes
Wq	Wea silt loam, 3-8 percent slopes, eroded
Wr	Westland loam, 0-3 percent slopes
Ws	Westland silt loam, 0-3 percent slopes
Wt	Westland silty clay loam, 0-3 percent slopes
Wu	Wingate silt loam, 0-3 percent slopes

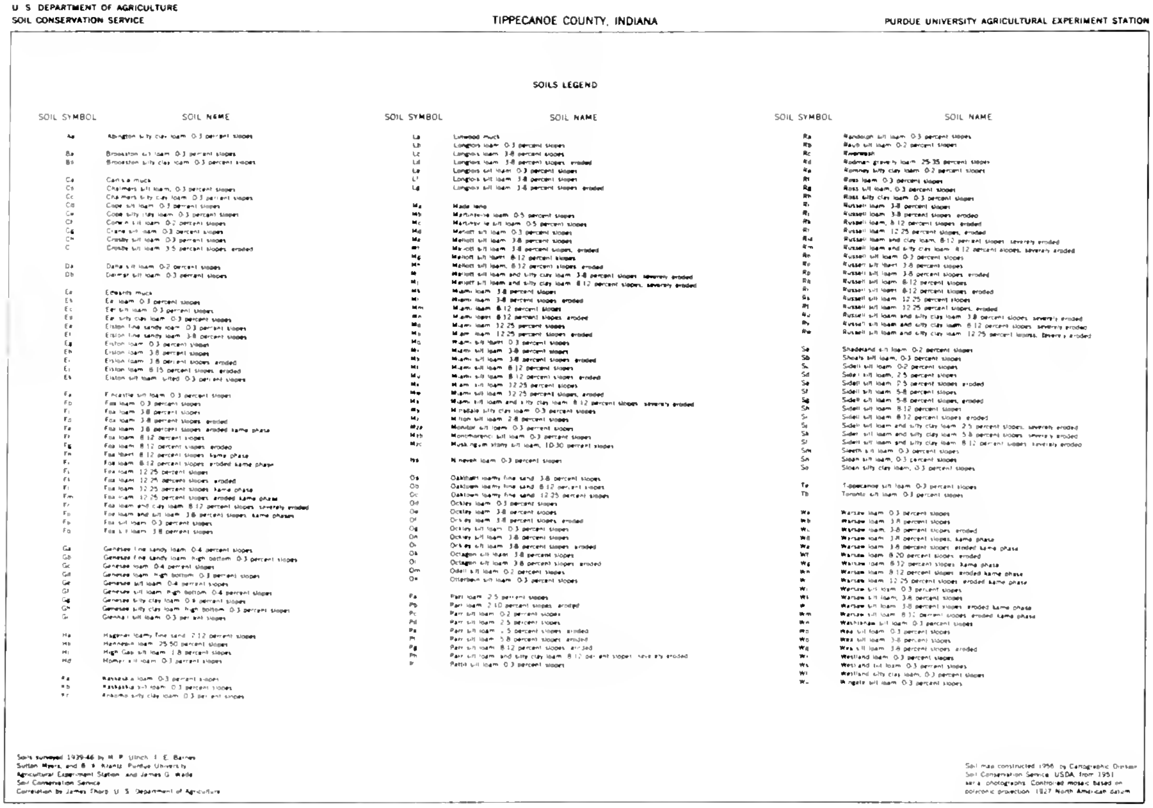
Soils surveyed 1939-46 by H. P. Ulrich, T. E. Barnes, Sutton Myers, and B. A. Krantz, Purdue University Agricultural Experiment Station, and James G. Wade, Soil Conservation Service. Correlation by James Thorp, U. S. Department of Agriculture.

Soil map constructed 1956 by Cartographic Division, Soil Conservation Service, USDA, from 1951 aerial photographs. Controlled mosaic based on polyconic projection, 1927 North American datum.

After ULRICH et al. (176)

FIGURE 35. PORTION OF TIPPECANOE COUNTY AGRICULTURAL SOILS MAP.


COUNTY INDIANA
Sheet 21
5
N
FAIRFIELD
Longlois Reserve
LAFAYETTE
Lafayette
WEA
(Sheet 6)
Scale 1:31 680
0
5000
10 000 Feet



After ULRICH et al. (176)

FIGURE 35. PORTION OF TIPPECANOE COUNTY AGRICULTURAL SOILS MAP

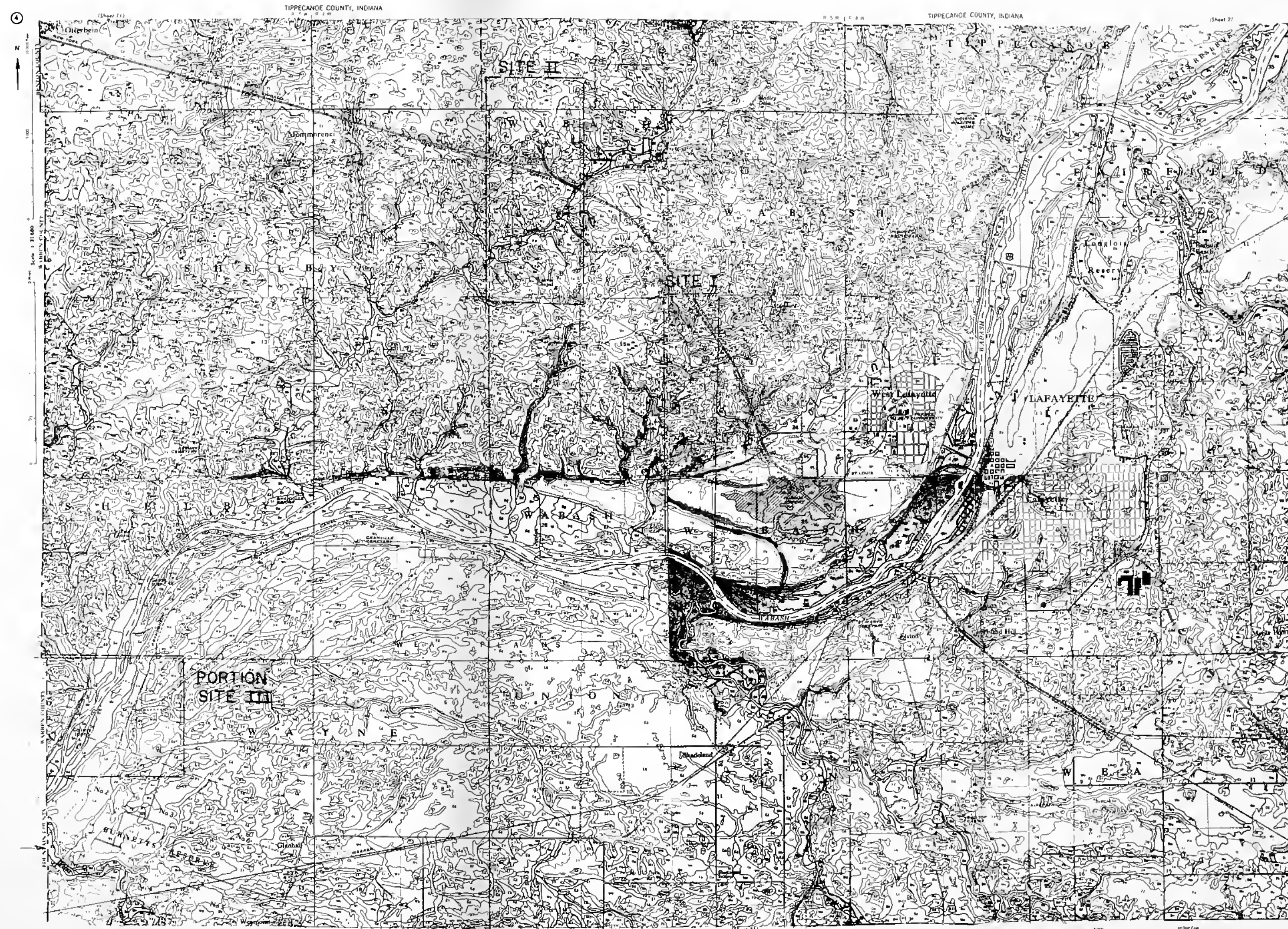


FIGURE 35

SCALE 1: 42,240

	Imagery Coverage[b]		
ared[e]	Radar[f]	Multi-Channel[g]	Agency[h]
, III	I, II, III	I, II, III	
, 2	K, K, K	--	WPAB
, 2	K, K, K	--	WPAB
, 2	--	--	WPAB
-	K, K, K	--	WPAB
-	K', K', K'	--	j
-	K', K', K'	--	j
-	--	--	ISHC
-	--	--	ISHC
-	--	--	ISHC
-	--	--	ISHC
-	--	- X X	ISHC,UM
,2;1,2	--	--	FS
,3;1,3	--	--	FS

atory, Wright-Patterson Air Force Base.
Highway Commission.
ptical Sensor Laboratory, Institute of
chnology, University of Michigan.
Forest and Range Experiment Station,
t Fire Laboratory, U.S. Forest Service.
ic coverage of test sites obtained on

developed by U.S. Army Electronics

the B&W of May 6, 1966 flown by
Commission. The May 6, B&W and the
flown by University of Michigan.
ned by the University of Michigan
and Technology under NASA Grant 715
the U.S. Army Electronics Command to
ent developed under Project MICHIGAN
C-00013(E).

Table 5. Flight Coverage of Test Sites.

	Photographic Coverage[a]						Imagery Coverage[b]			
Film Types[c]	B&W	B-I	C-P	C-N	C-I	Nine-Lens[d]	Infrared[e]	Radar[f]	Multi-Channel[g]	Agency[h]
Date	Site: I, II, III	I, II, III	I, II, III	I, II, III	I, II, III	I, II, III	I, II, III	I, II, III	I, II, III	
May 13, '65[i]	--	--	m, m, m	--	--	--	2, 2, 2	K, K, K	--	WPAB
July 1, '65	m,l;m,l;m,l	m,l;m,l;m,l	m,l;m,l;m,l	--	--	--	2, 2, 2	K, K, K	--	WPAB
July 26, '65	--	--	m,l;m,l;m,l	--	--	--	2, 2, 2	--	--	WPAB
Sept. 1, '65	m, m, --	--	m,l;m,l, --	--	m,l;m,l, --	--	--	K, K, K	--	WPAB
Sept. 14, '65	--	--	--	--	--	--	--	K′, K′, K′	--	j
Oct. 7, '65	--	--	--	--	--	--	--	K′, K′, K′	--	j
Oct. 25-26, '65	m,l;m,l;m,l	m,l;m,l;m,l	--	m,l;m,l;m,l	m,l;m,l;m,l	- m, m	--	--	--	ISHC
May 2, '66[k]	m,l;h,m,l;m,l	--	--	--	--	--	--	--	--	ISHC
3,	--	--	--	-- h,m,l;m,l	-- h,m,l;m,l	--	--	--	--	ISHC
4	--	--	-- h,m,l;ml	--	--	m, m, m	--	--	--	ISHC
6	- l, l	m,l;h,m,l;m,l	--	--	--	--	--	--	- X X	ISHC,UM
June 1 '66	--	--	--	--	--	--	1,2;1,2;1,2	--	--	FS
2	- 0 -	--	--	--	--	--	1,3;1,3;1,3	--	--	FS

a. Photographic Scales flown, 9 x 9 format:
   h - high altitude 1:24,000. l - low altitude 1:4,000
   m - medium altitude 1:10,000 0 - 70mm format, low altitude

b. All imagery obtained on this project is "classified". Prints from radar imagery of 9/14 and 10/7, 1965 and infrared imagery of 6/1 and 6/2, 1966 have been "declassified".

c. Film Types and Filters:
   B&W, Plus-X Aerographic Film with no.12 antivignetting filter on 10/65 and 5/66 flights. None on others.
   B-I, Infrared Aerographic Film with no.12 antivignetting filter on 10/65 and 5/66 flights.
   C-P, Ektachrome Aero Film (HF-3 only used on 5/13 flight).
   C-N, 1-Agfacolor Negative Film CN 17, used Oct. 25-26.
   2-Ektachrome MS Aerographic Film Type SO-51 (Aero-Neg.), used May 3.
   C-I, Ektachrome Infrared Aero Film with no. 12 antivignetting filter. None used on 9/1 flight.

d. Nine-Lens camera coverage from .38 to .89 microns in 8 steps. See Figure 36.

e. Infrared Imagery:
   1. 4.5-5.5 micron band, daytime.
   2. 8-14 micron band, nighttime.
   3. 8-14 micron band, daytime.

f. Radar Coverage:
   K - K band (HH) polarization
   K′ - K band (HH) and (HV) polarization

g. Multichannel coverage from ultraviolet through far infrared in numerous bands (details classified).

h. Agency:
   WPAB - Avionics Laboratory, Wright-Patterson Air Force Base.
   ISHC - Indiana State Highway Commission.
   UM - Infrared and Optical Sensor Laboratory, Institute of Science and Technology, University of Michigan.
   FS - Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, U.S. Forest Service.

i. Only partial photographic coverage of test sites obtained on this flight.

j. Obtained with equipment developed by U.S. Army Electronics Command.

k. All photography except the B&W of May 6, 1966 flown by Indiana State Highway Commission. The May 6, B&W and the multichannel imagery flown by University of Michigan.

The imagery was obtained by the University of Michigan Institute of Science and Technology under NASA Grant 715 with permission from the U.S. Army Electronics Command to use classified equipment developed under Project MICHIGAN contract DA-28-043-AMC-00013(E).

flights were evaluated to determine the effect of vegetative cover on the interpretation of soils information. These first four missions were flown by the Avionics Laboratory of Wright Patterson Air Force Base in Ohio. They agreed to obtain coverage of the test sites and furnish the information as part of one of their projects sponsored by NASA and GIMRADA[4]. These flights contained the largest number of sensors flown simultaneously over the test sites. During these flights, several passes were made with the imaging sensor equipment set at different gain levels. For the photographic coverage, two T-11 aerial cameras were available for simultaneous exposure.

The radar flights of September 14 and October 7, 1965 were actually not part of this project. Dr. D. S. Simonett of the Center for Research in Engineering Science (CRES) at the University of Kansas furnished a set of the "unclassified" (degraded) radar imagery coverage of the test area for these dates.

The October 25 and 26 flights were the first extensive flights planned for this project. The original plans were to have the Indiana State Highway Commission obtain coverage of the sites with the four film types listed in Table 7, and have the Wright Patterson Air Force group fly multisensor coverage using color positive and black-and-white aerial photography for their photographic coverage. Because of scheduling and equipment problems, the Wright Patterson group was unable to participate.

The flight by the highway department was extended over a two day period. This was necessary in order to obtain the exposures of the various film types during the prime hours of the day. A Wild RC-8 aerial

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[4]GIMRADA - Geodesy, Intelligence and Mapping Research and Development Agency, U. S. Army.

camera with a six-inch focal length was used on the project and a Number 12 Wratten filter corrected for vignetting effects was utilized as needed. Since only one roll of film could be exposed at a time, the flight schedule was planned so as to expose the black-and-white films in the early and late phases of the flight, and the color films around noon time. This was the highway department flight crews first experience with exposing and developing the color films, and they did a commendable job.

Based on an analysis of all the information obtained, the May 1966 flight was planned. This was to be the final and most complete flight of the project. Once more, the Wright Patterson group was unable to participate. To obtain the necessary coverage by other sensors, arrangements were made through the LARS group to have the Infrared and Optical Sensors Laboratory of the University of Michigan obtain coverage of the test sites. Arrangements were also made with the Northern Forest Fire Laboratory of the U.S. Forest Service to obtain coverage of the test sites since it was not certain until about a week before the flight whether the Michigan group would be available.

The final flight was accomplished during the week of May 2-6, 1966. The coverage by the highway department was planned to be completed within a two day period; however, delays in the delivery of the film by the film manufacturer extended this period to a full week. This did not adversely affect the project, as complete simultaneous coverage of the test sites from the ultraviolet through the visible and into the far infrared was obtained during this period by the multichannel equipment of the University of Michigan. The various film types flown by the

Indiana Highway Commission were successfully exposed and developed by the organization and excellent results were obtained.

The final flights in this research project were flown by the Forest Service on June 1-2, 1966. This was the only flight of the project in which nighttime infrared imagery was also obtained for analysis. Imagery in the 4.5-5.5 and the 8-14 micron bands was obtained both during the day and night.

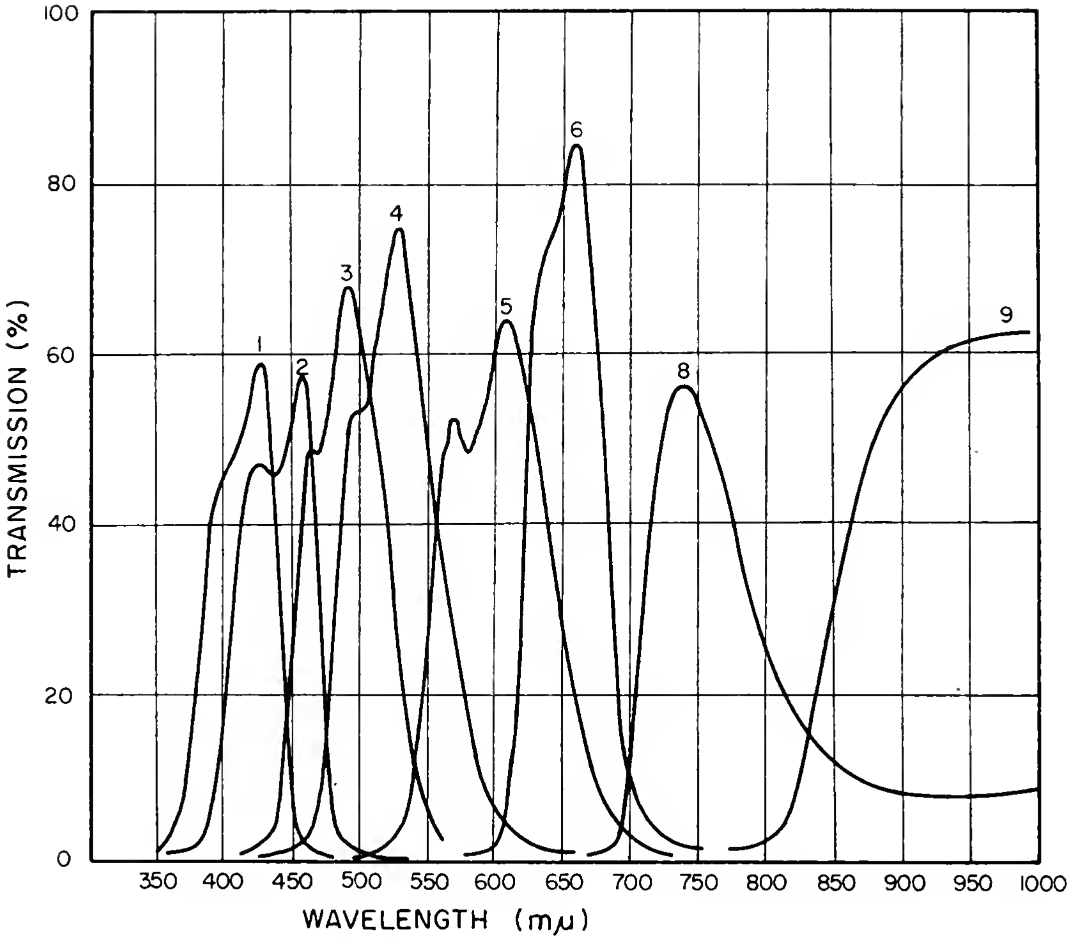
During the October 1965 and May 1966 flights, a nine-lens camera on loan from the University of Michigan was utilized on the project. A limited number of aerial and ground exposures were taken at these times. This camera was filtered so that the spectrum from 0.38 microns to 0.89 microns was divided into eight narrow bands (one per lens) with the other lens covering the full range. Details of the bands and their ranges of response are shown in Figure 36. Glass 1-N spectroscopic plates were used in this camera.

A perusal of Table 5 indicates that an extensive coverage of both photography and imagery was obtained for this project study. Various sensors and sensor systems were utilized and various photographic film types obtained. Although, at any given time, simultaneous exposures of all film types and sensors were not obtained (the ideal situation for a multisensor project), nevertheless a comprehensive program was accomplished.

Evaluation of Data - Qualitative Approach

Procedure

In engineering soils mapping projects utilizing aerial photographic interpretation techniques, black-and-white photography has been the basic



LENS NO.	BAND WIDTH (mμ)
1	380 - 440
2	410 - 470
3	450 - 520
4	480 - 560
5	550 - 640
6	620 - 680
8	710 - 790
9	850 - 890
7	FULL RANGE

(COURTESY UNIVERSITY OF MICHIGAN)

FIGURE 36. NINE-LENS MULTIBAND CAMERA SYSTEM OF THE UNIVERSITY OF MICHIGAN.

type used. Therefore, in this project, all other types of photography and imagery evaluated were compared to the black-and-white photography. The value of the other types were determined on the basis of what additional, or more accurate information they furnished above that obtained from the black-and-white photography.

The procedure followed for the qualitative evaluation of the data included the following steps:

1. Interpretation of the individual film and imagery types obtained for a given flight;

2. Comparison of the individual types to the black-and-white photography to determine additional information furnished;

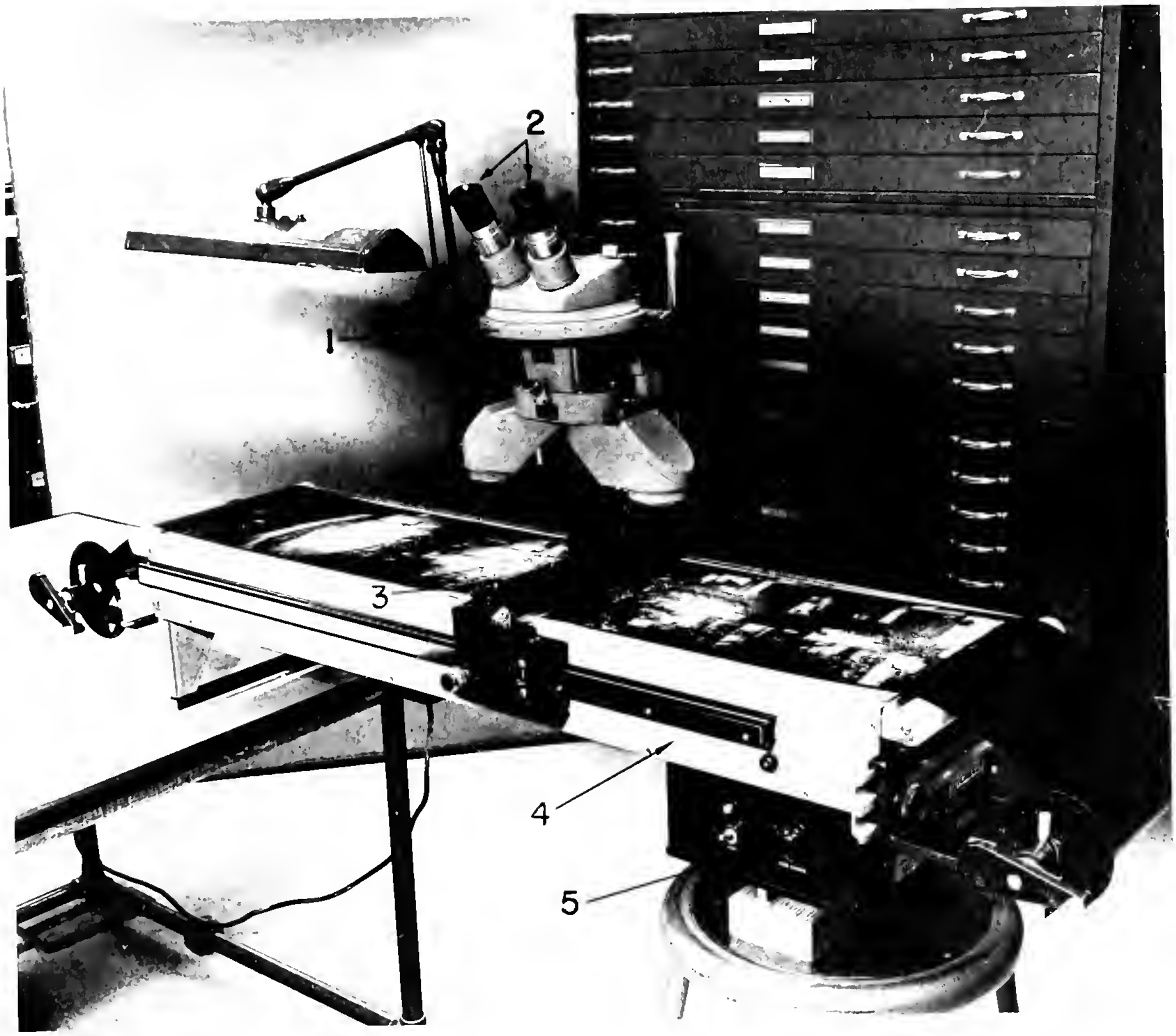
3. Evaluation of all the photography and imagery obtained in a given flight to determine the amount and type of information obtained;

4. Evaluation of the information obtained from a given flight and all previous flights to plan the flight program for the following flight; and

5. Comparison of the information obtained from all the flights to arrive at the optimum multisensor system for engineering soils analyses and to determine the best season for obtaining coverage.

Equipment Utilized for Interpretation

Stereoscopic coverage was obtained for all aerial photographic film types. The equipment used to study the photography stereoscopically and imagery monoscopically are shown in Figure 37. The viewer used was a Bausch and Lomb Zoom 95 Stereoscope with capabilities of continuous magnification from 2.5 to 20 times in two stages. The stereoscope was mounted on a microscope carriage on a light table (Richards Model GFL-940)



1. ZOOM STEREOSCOPE
2. EYEGUARDS
3. MICROSCOPE CARRIAGE
4. LIGHT TABLE
5. LIGHT INTENSITY CONTROL

FIGURE 37. EQUIPMENT USED FOR QUALITATIVE ANALYSIS.

enabling scanning in an X and Y direction. The light source was an argon-mercury source which provided 900 foot lamberts at maximum intensity. A light intensity control was available on the light table allowing a continuous variable intensity at a 20 to 1 ratio in two overlapping ranges. Both transparencies (positives and negatives) and positive prints were viewed on the light table. To view the positive prints, the prints were placed and secured on the table and illuminated by an external source.

Interpretive Techniques

Two special techniques were utilized in the analysis of the photography which greatly assisted in the interpretation. These were the use of special Wratten filters in the viewing system when interpreting the color photography and the use of backlighting when viewing positive prints on the light table.

Use of Wratten Filters. The use of special filters was found to increase the contrast between target materials present on color photography. This technique made it possible to delineate various soil boundaries more easily. The filters utilized were Wrattens 25, 47 and 58. These were the same filters used in the reflection densitometer for making quantitative measurements. The densitometer was used to determine the filter that gave maximum contrast and this filter was used for interpretation of the photography. Two filters were initially used and were cut to size to fit in the eye guards (item 2 Figure 37). This method decreased the light considerably to the point where less information was obtained than without the filters. It was found that using only one filter (placed in the left eyeguard which had the adjustable lens), it

was possible to obtain the desired contrast without excessive suppression of light.

Use of Backlighting. The use of backlighting for viewing positive prints on the light table was found to be very helpful. It decreased the glare obtained from the surface of the print and at low backlighting levels, it appeared to increase the contrast between objects. This increase in contrast was not a continuous effect but decreased as the amount of backlighting was increased.

This phenomenon was investigated by performing successive densitometric scans (using the visual filter) over the positive prints as the amount of backlighting was increased. Six scans were performed in each range. Figure 38 shows three of the scans obtained in each range. An analysis of the scans indicated that the amount of detail obtained was essentially the same on each scan (i.e., the number of deflections about the same). The only change noted is that the whole scan is shifted indicating an overall increase in brightness. However, the contrast between objects remains about the same (i.e., the height of deflections about the same). These curves would indicate that the apparent increase in contrast is a psychological phenomenon.

Evaluation of Data - Quantitative Approach

Procedure

Densitometric scans were made on the various types of photography obtained. Continuous scans and point readings were taken for selected portions of the photography. The purpose of this was to determine if typical density patterns existed for the various land forms present in

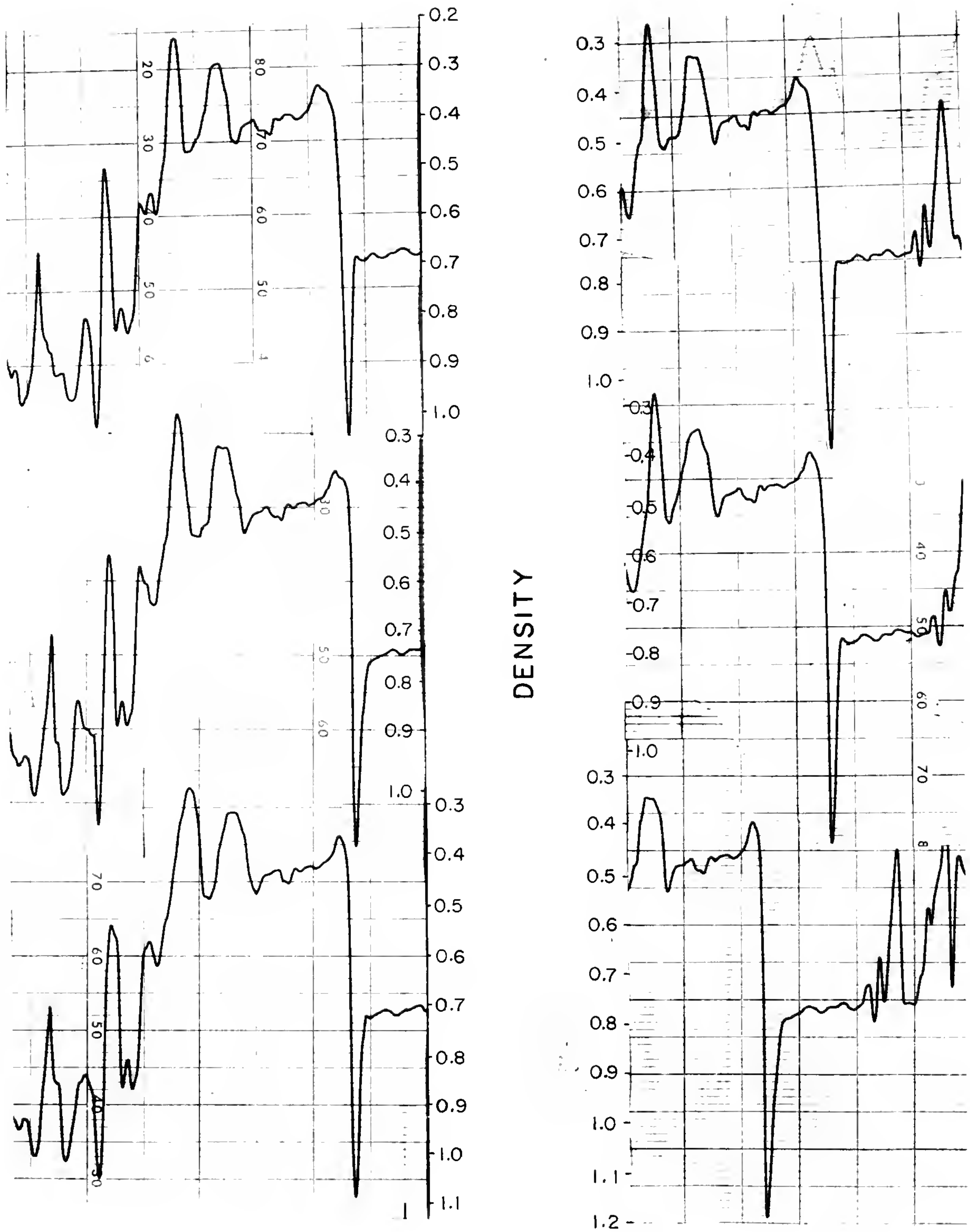


FIGURE 38. DENSITOMETER SCANS INDICATING EFFECT OF BACKLIGHTING.

the test areas. The measurements performed in this phase included the following:

1. Three continuous densitometric scans were made along the length of each test site to determine if typical patterns were present for the various land forms;

2. Continuous densitometric scans were performed along three chosen lines in a selected area. Along these lines, reflection and transmission measurements were made on various film types (positives and negatives) with all four filters available on the densitometers (visual, red, blue, green). Scans also were made for the same film type at various times of the year, and for two different film types at six different aperture openings. Aperture openings used were 3mm, 2mm and 1mm which were available with the transmission densitometer used on this project. Scans utilizing 0.2mm, 0.02mm and 0.001886mm openings were performed for this project by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), on an Ansco microdensitometer;

3. Continuous densitometric scans were performed along two chosen lines to determine the effect of three different scales of the photography on the scan pattern. Scan rates were selected so that the final length of the scans at the different scales were the same;

4. Point readings on a one-half inch grid pattern were measured with the four filters for selected areas;

5. Densitometric readings using the four filters were made on all the color chips in the Munsell Book of Color (128); and

6. Densitometer readings were taken of selected points on the various bands of the multichannel imagery.

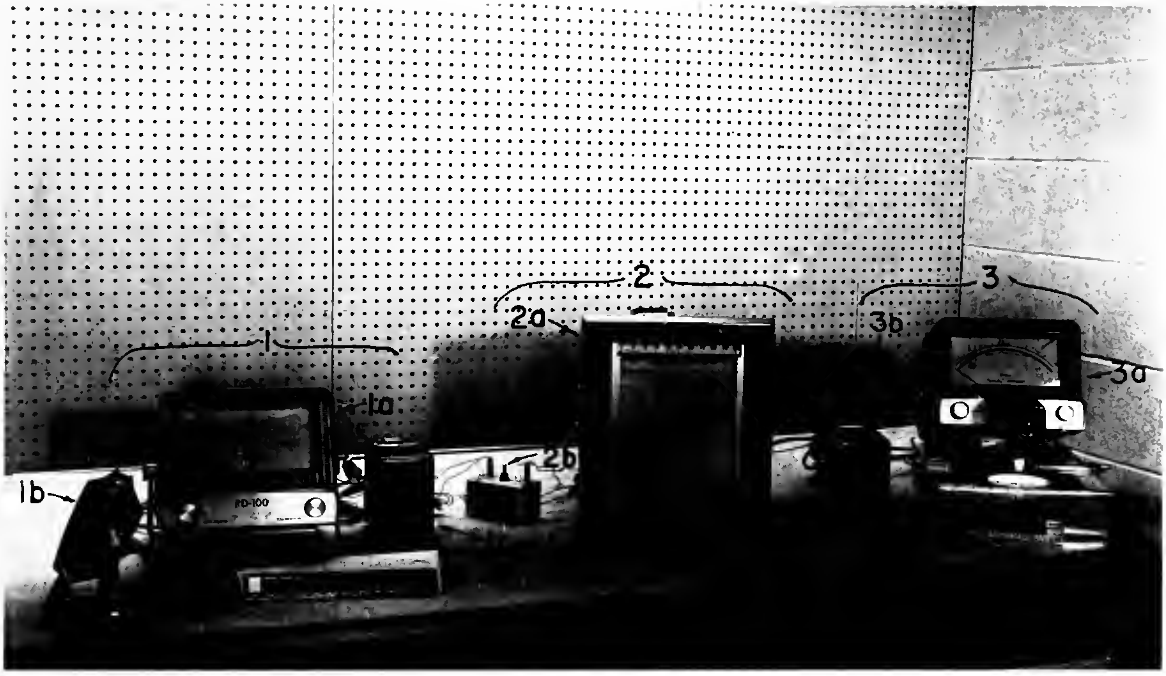
The measurements were used to evaluate the potential applications of densitometers for automatic interpretation of land forms and the effect of certain parameters on this technique. Some of the parameters studied included: (1) differences due to film type; (2) differences due to filters; (3) differences due to measurements on positive or negative films; (4) differences due to season; (5) differences due to aperture opening; and (6) differences due to scale of photography. Also studied were the possibility and value of preparing isotonal maps for both black-and-white and color photography.

An additional major area of quantitative investigation was the use of densitometer readings of the Munsell color chips to develop a rapid and automatic system to determine the Munsell color of target materials on the color photography. Various aspects of this portion of the study will be discussed in a later section.

The final area of densitometry investigated was that of measuring the density of various target materials on the multichannel imagery. The purpose of this phase was to evaluate which bands were most useful for identification of the various target materials of interest. An ancillary purpose was to obtain an indication of the spectral response of various target materials in the different spectral regions investigated.

Equipment Utilized for Quantitative Analysis

The densitometers and necessary accessory equipment utilized in this project are shown in Figure 39. The densitometers used were the Macbeth QuantaLog Densitometer Model RD-100 (see 1, Figure 39) for obtaining reflection density readings from prints and the Macbeth



I. COMPONENTS OF REFLECTION DENSITOMETER

1a.- REFLECTION DENSITOMETER CONTROLS & METER
1b.- MEASURING PROBE AND FILTER SELECTOR
1c.- 30 VA SOLA VOLTAGE REGULATOR
1d.- 10 STEP CALIBRATED REFLECTION PLAQUE

2 COMPONENTS OF CHART RECORDER

2a.- CHART RECORDER
2b.- VOLTAGE DIVIDER UNIT

3. COMPONENTS OF TRANSMISSION DENSITOMETER

3a.- TRANSMISSION DENSITOMETER
3b.- 60 VA SOLA VOLTAGE REGULATOR
3c.- 20 STEP CALIBRATED TRANSMISSION TABLET 0-4.0 DENSITY

FIGURE 39. EQUIPMENT USED FOR QUANTITATIVE ANALYSIS.

QuantaLog Densitometer Model TD-102 (see 3, Figure 39) for obtaining transmission density readings from transparencies and negatives.

The reflection densitometer measured an area on the print 4mm in diameter. The filters used in the probe included Wrattens 106W (visual) 25 (red), 47 (blue) and 58 (green). The transmission densitometer had interchangeable apertures of 1mm, 2mm and 3mm in diameter. The filters used in this instrument included Wrattens 106W (visual), 92 (red), 93 (green) and 94 (blue). Both of these densitometers are point measuring densitometers; therefore, a technique had to be developed to use these instruments for making continuous scans. The technique developed will be described subsequently.

The recorder utilized was a Leeds & Northrup Speedomax H Compact Azar Recorder (see item 2, Figure 39). Special features of this recorder include an adjustable span, adjustable zero and a six speed chart selector. To balance the output of the densitometers to that of the recorder a simple voltage divider was constructed (see item 2b, Figure 39). The schematic for this unit is shown in Figure 40. The voltage divider

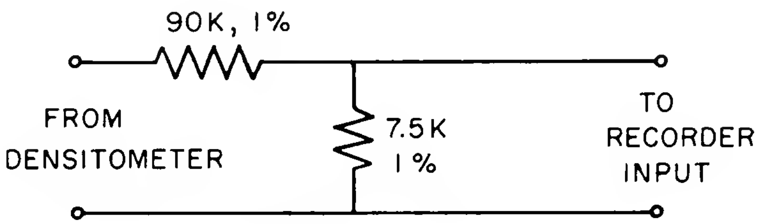


FIGURE 40. SCHEMATIC OF VOLTAGE DIVIDER.

unit was placed in a control unit with a three position switch so that either of the densitometers could be attached to the recorder or else the recorder could be taken out of the circuit. The calibration of the recorder-densitometer units for various full-scale density readings (e.g., 0-1.5 density equivalent to 100 units on chart) are included in Appendix B, Figure B.2 and B.1 for RD-100 and TD-102 respectively.

Continuous Scanning Techniques

A simple technique was developed to obtain continuous scans from the point reading densitometers. The basic techniques are demonstrated in Figure 41. The technique for scanning with the RD-100 is seen in Figure 41a. The photograph is mounted on a board (item 1) and a T-square (item 2) clamped in position so that the scan can be performed along any chosen line. The probe is pulled manually across the board at a given rate (normally one inch every few seconds). A stop watch (item 3) is used so that the operator can check his progress continuously. The chart speed on the recorder is usually set at the same speed as the scanning rate so that one inch on the photograph would equal one inch on the chart. This enables direct comparisons to be made.

The technique for scanning the transparency is similar to that used for prints, except a more elaborate procedure is needed since the recording head can not be moved on this unit. This technique is demonstrated in Figure 41b. First, the neoprene "O" ring on the head of the TD-102 (item 1) had to be replaced with a teflon ring to decrease the friction between the head and the photograph so that the photograph could be pulled through uniformly. A cork of proper size (item 2) was placed in position over the lever on the head to maintain a complete

(a) TECHNIQUE FOR SCANNING WITH RD-100

(b) TECHNIQUE FOR SCANNING WITH TD-102

(NOTE: SEE TEXT FOR DISCUSSION OF NUMBERED ITEMS)

FIGURE 41. TECHNIQUES FOR SCANNING WITH DENSITOMETERS.

circuit during the course of the scan. A special film holder (item 3) was built so that the film could be properly positioned in order to scan the desired line. A sliding clamp unit (item 4) was required so that the holder could be positioned for scanning parallel to any desired line. A scale unit (item 5) was used so that the operator could control the rate at which the holder was pulled across the densitometer head. A stop watch (item 6) was used for control.

Although these techniques are subject to inaccuracies in the exact positioning of an object, good results were obtained by these methods. Four different operators were trained in a relatively short time and could obtain satisfactory results. The main problem was the difficulty in maintaining constant speed throughout the scan. Checks at inch lines indicated the operators were less than 0.05 of an inch from true position while within the inch lines, the points were in most cases no more than 0.10 inch off. This was close enough to identify any point desired so that comparisons between scans could readily be made. For the needs of this project, this accuracy was satisfactory. Where more accuracy is desired, a device could be constructed to give constant scanning rates.

A variation of this technique was used for the case where it was desired to compare the amount of detail obtained over a given line at different scales of photography. In this case, the chart speed and rate of scan were adjusted for each scale of photography so that the final length of the scan line was the same for each scale.

Climate and Geology of Test Sites

The test sites are located in the Tipton Till Plain physiographic region [Malott (104)]. As discussed by Woods and Lovell (191, page 9 - 37, 38), the Tipton Till Plain is part of the Central Till Plains Section of the Central, Arctic, and Eastern Lowlands and Plains of the Interior Plains physiographic provinces of North America (modified for engineering purposes). This province is characterized by little relief and only slight modification of surface features by post-Wisconsin streams. Within the project area, glacial drift overlies the bedrock surface in thicknesses varying from a thin veneer where bedrock is exposed, to over three hundred feet where pre-glacial valleys such as the Teays have been filled with drift (108)(187). Where bedrock highs were present, they influenced the glacial deposition. Figure 42 shows a portion of the map by McGrain (108) indicating the thickness of glacial drift in the test areas and vicinity. This figure indicates that some deep drift filled valleys (Teays and its tributaries) are passing beneath or in the vicinity of the test sites (108)(187).

The climate of the test area is continental, humid and temperate. The average annual precipitation is 38.26 inches. Approximately 60 percent of this falls during the period of April through September. The original vegetation of approximately two-thirds of the area consisted of mixed hardwood forests while the remainder was under prairie or grassland vegetation. At present, over 90 percent of the area is in farms and little of the original vegetation remains (176).

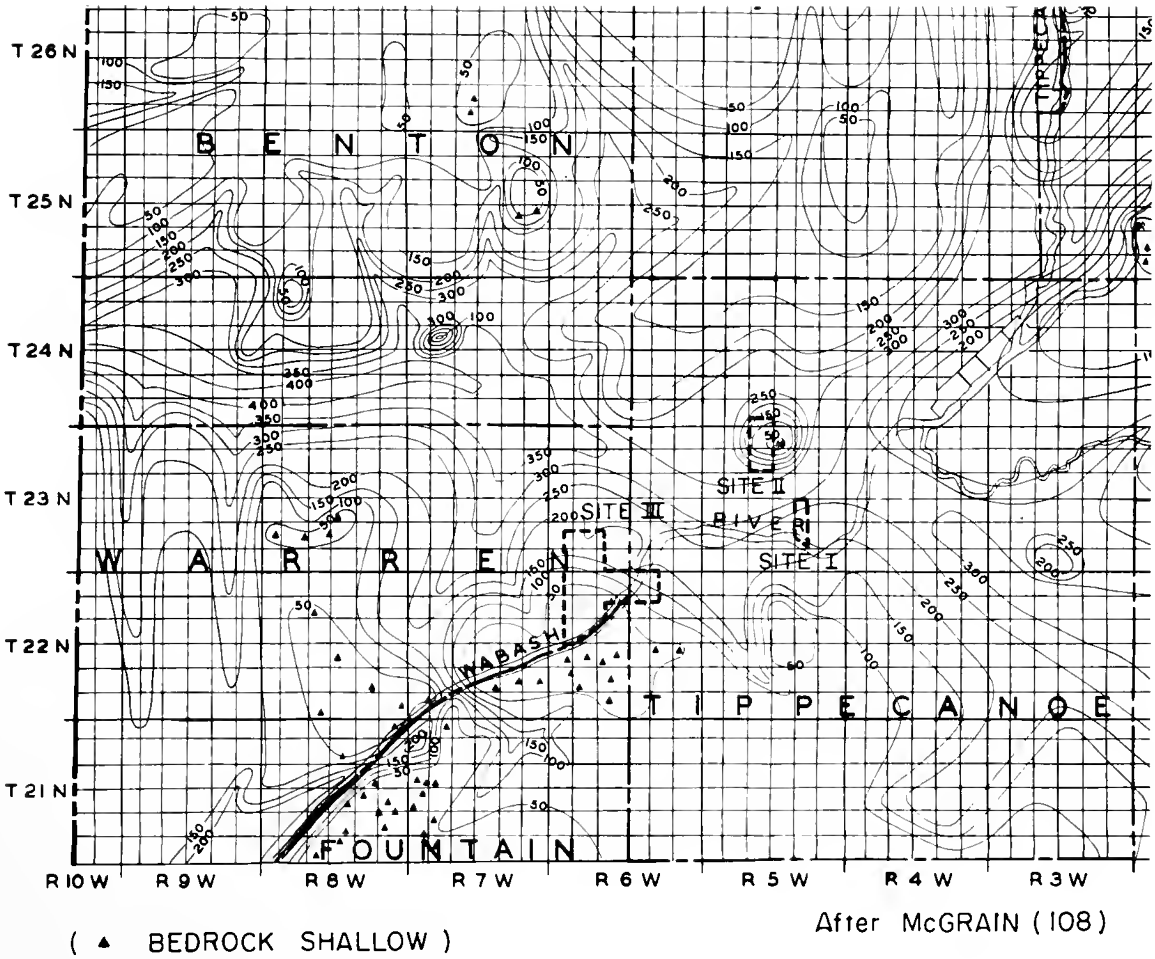


FIGURE 42. THICKNESS OF GLACIAL DRIFT.

Site I

The surface features for site I are indicated on the Tippecanoe County Engineering Soils Map, Figure 34. The land forms present include flood plains, sand dunes, terraces and moraines. Borings, well logs and geophysical investigations reported by Leonards et al.,(90) and Rosenshein and Cosner (152) indicate that the depth to bedrock varies from about 200 feet underneath the terrace and flood plains to almost 400 feet underneath the moraine in the northern part of Area I. Several reports (90)(108)(152)(187) suggest the possibility that the Teays Valley system passes somewhere under this site. The logs for wells and borings in the moraine also indicate the presence of interlayering of unsorted tills and water sorted layers suggesting that deposition was by ablation from a stagnating and melting ice sheet (90).

Site II

The surface features for site II are also indicated on the Tippecanoe County Engineering Soils Map, Figure 34. Land forms present include flood plains, terraces, both ridge and ground moraines, a boulder belt, and rock outcrops. The report accompanying this map also reports that the area is covered by a thin layer of loess (192). The Tippecanoe County Agricultural Soil Survey Map, Figure 35 and accompanying report indicate that in this site there is a transitional change from glacial till soils developed under forest conditions to glacial till soils developed under prairie grass conditions. The soils developed under forest conditions (referred to as Grey-Brown Podzolic soils in agricultural report) are indicated by the Russell and Fincastle soil series (Symbols Ri to Rw and Fa respectively). Those developed under prairie grass

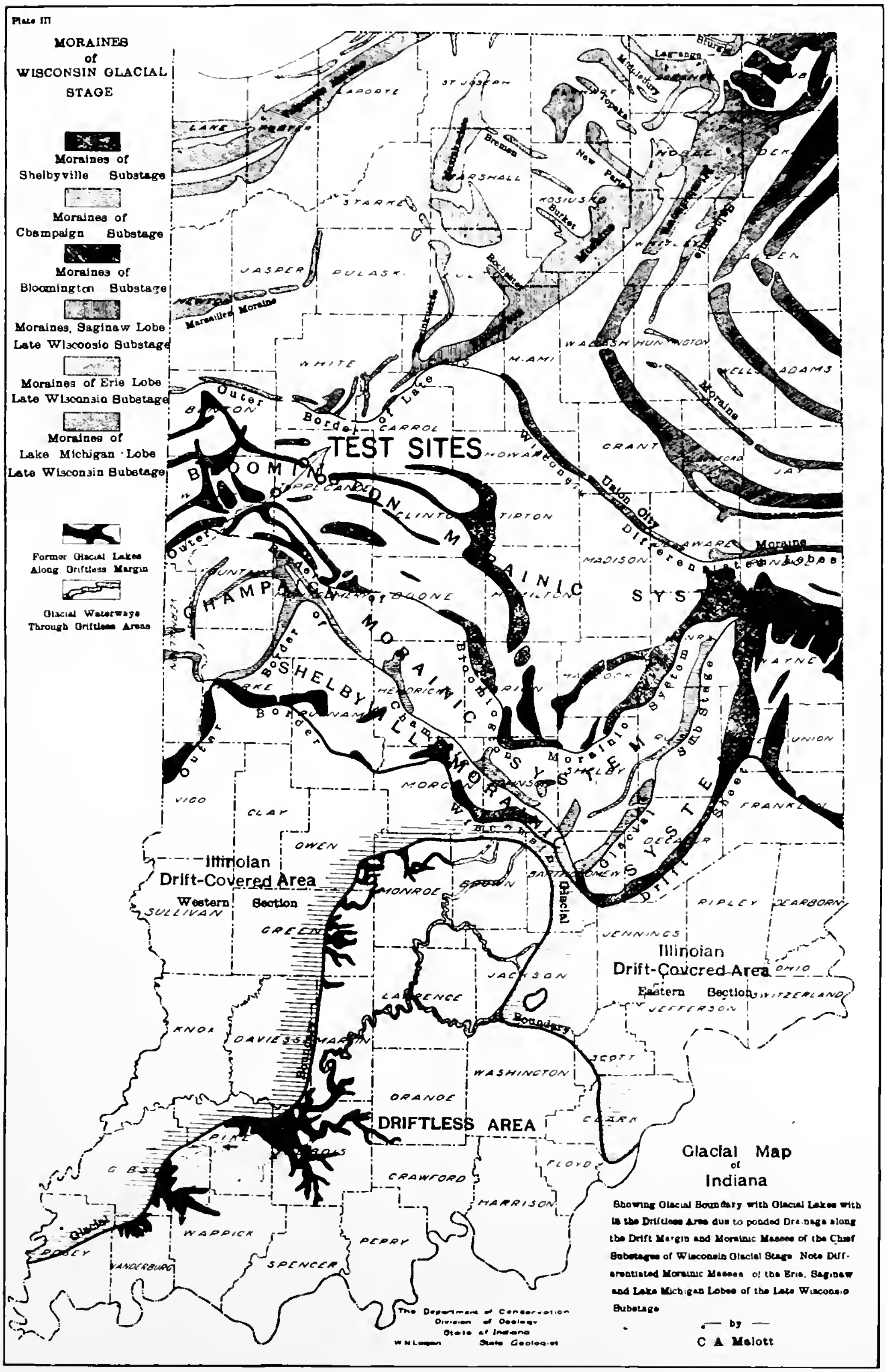
conditions (referred to as Brunizems) are indicated by Sidell, Dana, Raub soil series (Symbols Sc to Sl, Da and Rb respectively). Transitional soils between these two are the Mellott, Wingate, Toronto soil series (Symbols Md to Mj, Wu and Tb respectively)(176).

Bedrock, consisting of a silty shale of the Borden Formation (Lower Mississippian) is exposed in a quarry adjacent to the site (90). Logs of borings in the vicinity (90)(152), as well as limited resistivity surveys performed as part of the field exploration program showed that this near surface bedrock is limited in size and deepens rapidly on the side of Indian Creek, while to the North, it is thirty to fifty feet below the surface within a quarter of a mile. Borings also showed the presence of granular deposits interspersed with some till layers present in Indian Creek.

The small ridge moraine and boulder belt present in the area are part of the Bloomington morainic system. This is shown in Figure 43, the Glacial Map of Indiana and has also been reported by Leverett and Taylor (91, page 111).

Site III

In contrast to the other two sites, there was very little background information available for Site III except for that portion of the area located in Tippecanoe County. This site was chosen as a test site because it contained an extensive area of bedrock at shallow depths. It was also intended as a check site to see if similar conclusions would be obtained as to an optimum sensor system for an area where less background information was available. The surface features present for a portion of the site are shown in Figure 34 and Figure 43. Land forms indicated



After MALOTT (104)

FIGURE 43. GLACIAL MAP OF INDIANA.

include outwash plains, terraces, floodplains, a bedrock bench, organic basins, sand dunes, ground moraines and the presence of bedrock exposures on the valley walls on the north side of the Wabash River. The limited borings and published geologic data for Site III indicate that Mansfield Sandstone (Lower Pennsylvanian) rests unconformably on units of silty shales of the Borden Formation (Lower Mississippian) (44) (115). Field inspection, resistivity surveys and photo interpretation of the area indicate that the Mansfield Sandstone is fairly thin (generally less than 30 to 40 feet thick) and has been removed by erosion over much of the area. The field investigations and photo interpretation also indicate the presence in the test area of a morainic system with granular knolls which may be part of the Bloomington Moraine system (refer to Figure 43). Other geologic features noted are the narrowing of the valley of the Wabash River and the presence of the large outwash terrace adjacent to this site. Thornbury has attributed the narrowing of the Wabash River valley in this vicinity to the presence of the Mansfield Sandstones. He also attributes the presence of the large outwash plain to the joining of the old Anderson Valley system, a major tributary, with the Teays Valley at this point (174). The old Teays Valley is also indicated as passing just north of Green Hill, the northern most point of Site III (67).

Field Investigations

Two types of field investigations were performed in the course of this project. These included (1) field exploration programs to obtain a better understanding of the surface and subsurface features of the test sites, and (2) the collection of ground truth at the time of overflights

to assist in evaluating the various parameters affecting the photography and imagery.

Field Exploration Program

Field explorations were performed in order to obtain a better understanding of the surface and subsurface features of the test sites. The exploration program consisted of resistivity surveys to extend subsurface information from the limited number of wells and borings available, and field observations of the soil and rock profiles exposed. A limited amount of hand augering was carried out in conjunction with the resistivity surveys to obtain information on the upper layers of the surface soils.

Resistivity surveys were performed in portions of sites II and III. The equipment used for the survey was a portable earth resistivity meter utilizing low frequency alternating current. The method of survey was the variable-spacing or electric-drilling technique and the Wenner electrode configuration was used with the Lee-Partioning system.[5]

Resistivity Survey, Site II. A limited number of resistivity surveys were performed at Site II. The purpose of these surveys was to complement the subsurface information on the extent of the bedrock surface obtained from well logs, drill holes, and other resistivity surveys previously performed. Figure 44 shows the location of the resistivity surveys. The resistivity values for all points are tabulated in Tables A.1 and A.2 in Appendix A.

Typical resistivity curves obtained are shown in Figure 45.

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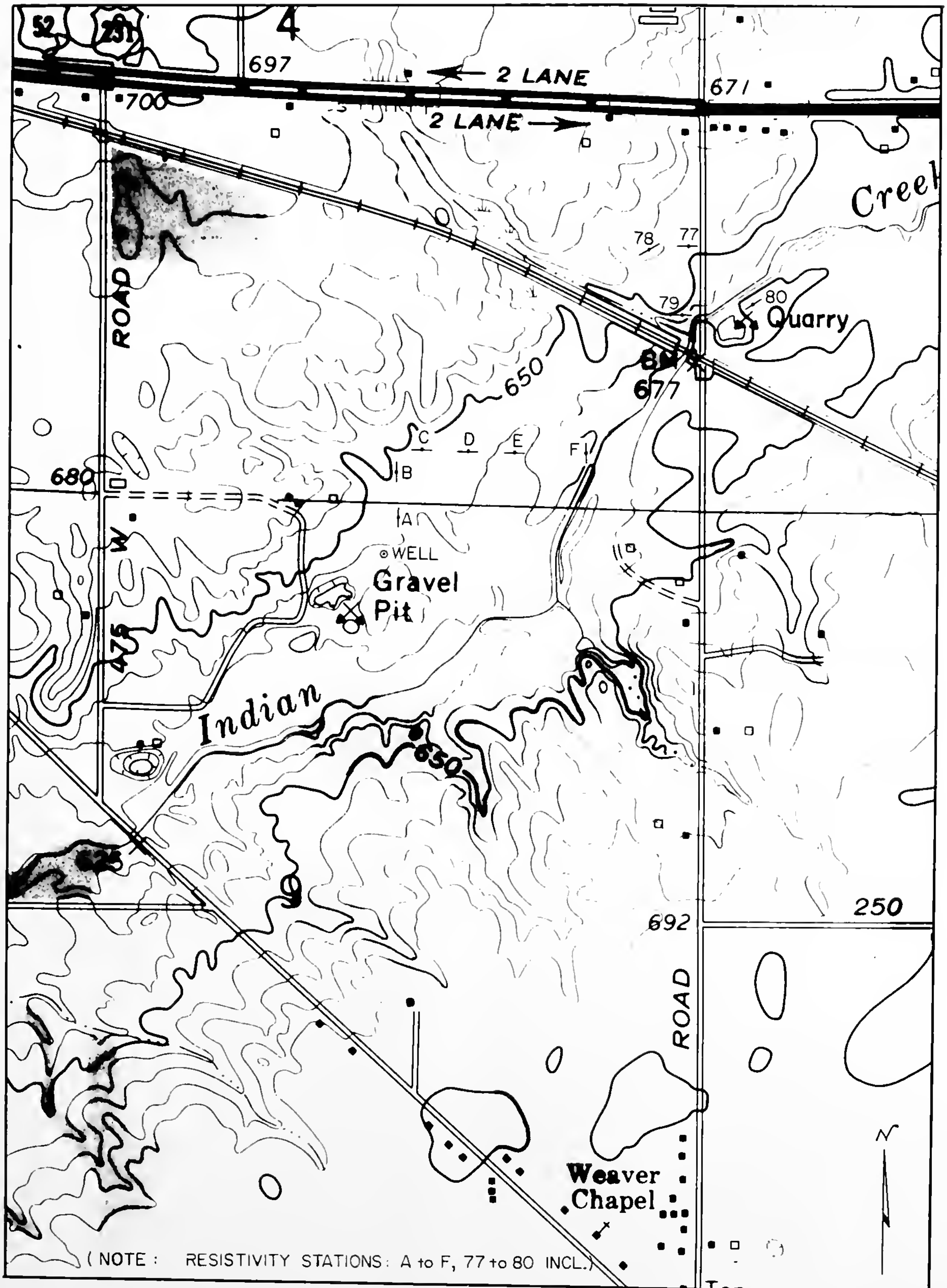
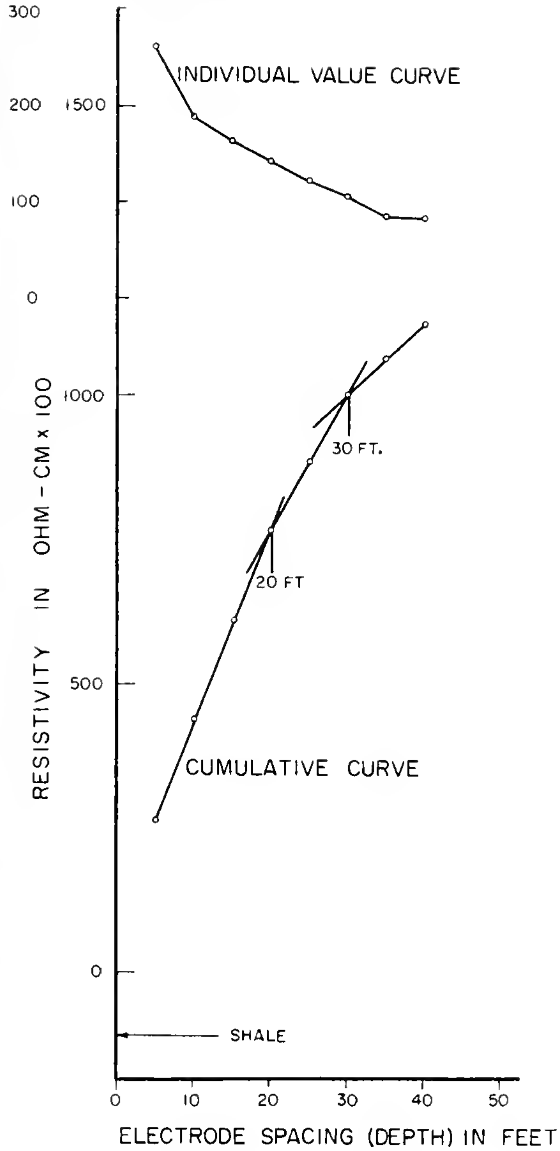
[5] More details on the survey technique can be obtained in the article by Johnson (69) and Chapter 17 of the book by Dobrin (37).



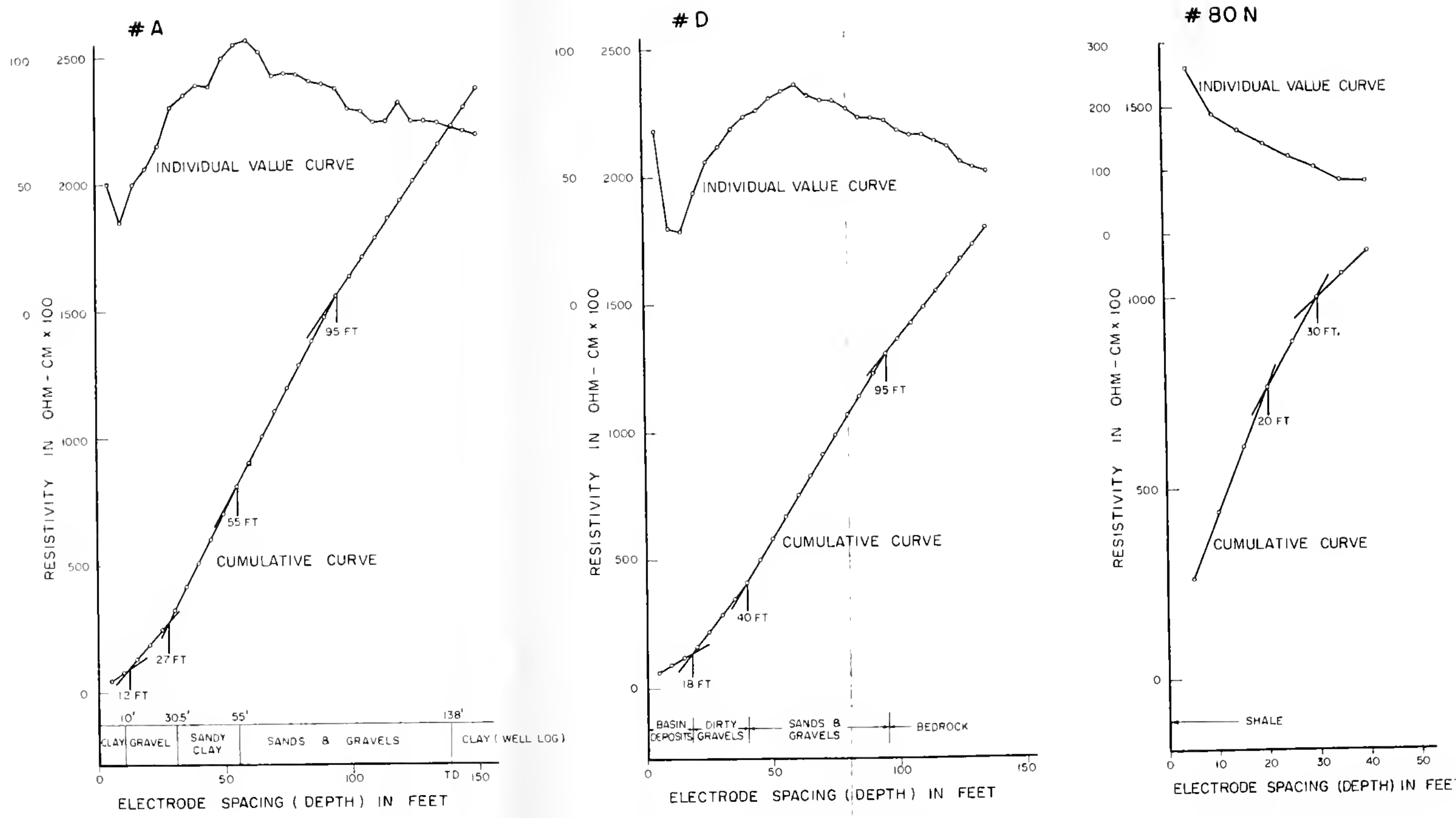
SCALE 1 : 12,000

FIGURE 44. LOCATION OF RESISTIVITY SURVEYS – SITE II.

80 N



(c) SHALE BEDROCK



(a) INTERLAYERED TILLS AND GRAVELS

(b) INTERLAYERED DEPOSITS OVER BEDROCK

(c) SHALE BEDROCK

FIGURE 45. TYPICAL RESISTIVITY CURVES FOR SITE II.

Figure 45a shows the typical curve obtained for resistivity surveys in the valley of Indian Creek. The log shown at the bottom is for a well located approximately 230 feet to the southwest of the survey point. The breaks coincide fairly well with the well log except that there is an indication of a thinning of the lower gravel layer. Figure 45b shows evidence of shale bedrock beginning at about 95 feet. The breaks included at the bottom of the graph show the layers which have been interpreted from the curve. The presence of basin deposits in the area containing this survey point have been indicated in the agricultural soil survey report and are also evident on the aerial photographs. Figure 45c shows the typical curve obtained for shale bedrock at a shallow depth. The breaks at 20 and 30 feet are probably an indication of the depth of weathering and a change in type of shale bedrock as well as surface soil changes as electrode spacing increases with increased depth.

Resistivity Surveys, Site III. Resistivity surveys were performed at limited areas of Site III in order to obtain more information on subsurface conditions to supplement the meager data available. The location of the resistivity points for which extensive analyses were made are shown in Figure 46. The detailed resistivity values for all of the survey points (including those not analyzed in detail) are tabulated in Table A.2 in Appendix A.

Typical terrain profiles for the soil and rock conditions found in the area and typical examples of the resistivity curves obtained are shown in Figure 47. Figure 47b represents the typical resistivity curves obtained for the conditions represented by profile 1 in this figure.

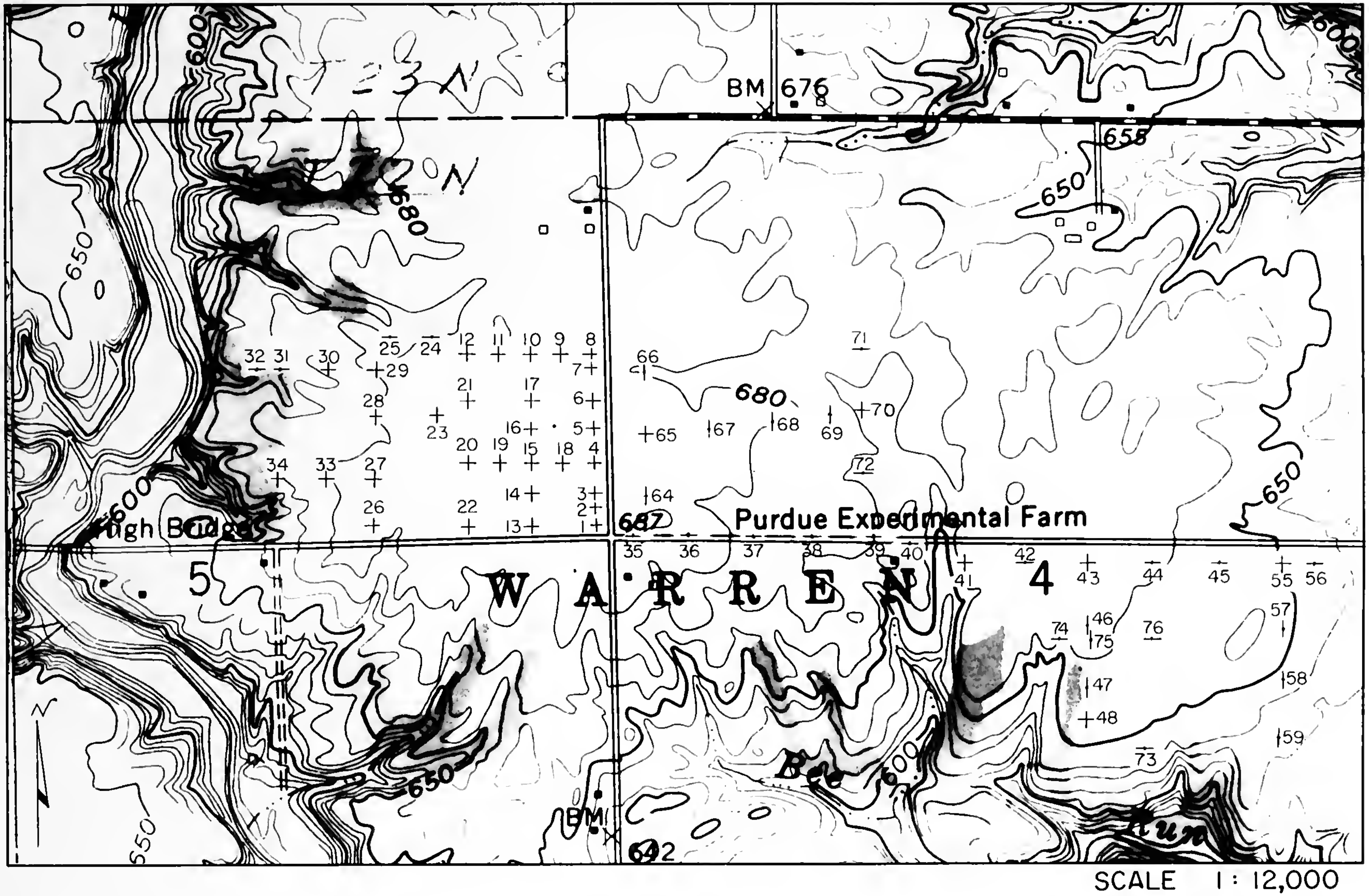
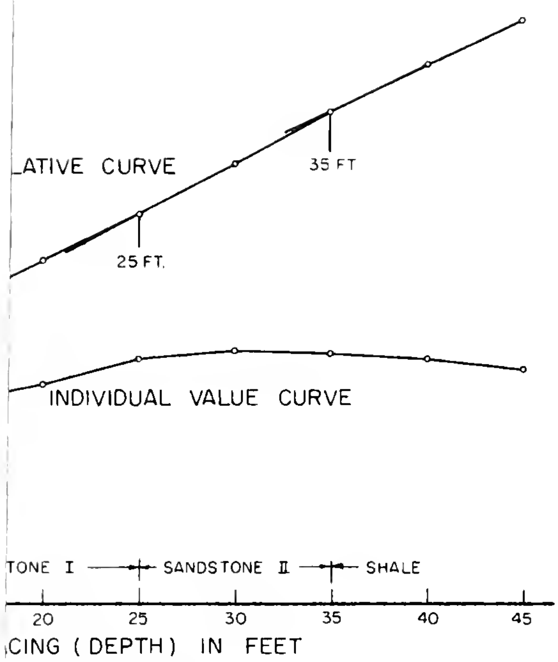
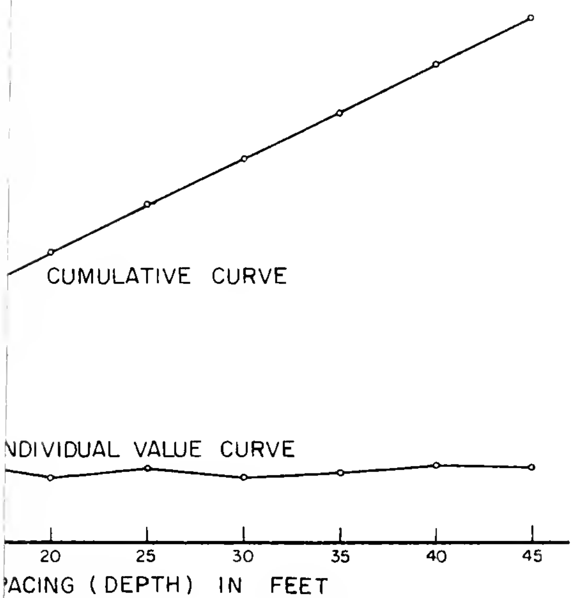


FIGURE 46. LOCATION OF RESISTIVITY SURVEYS – SITE III.

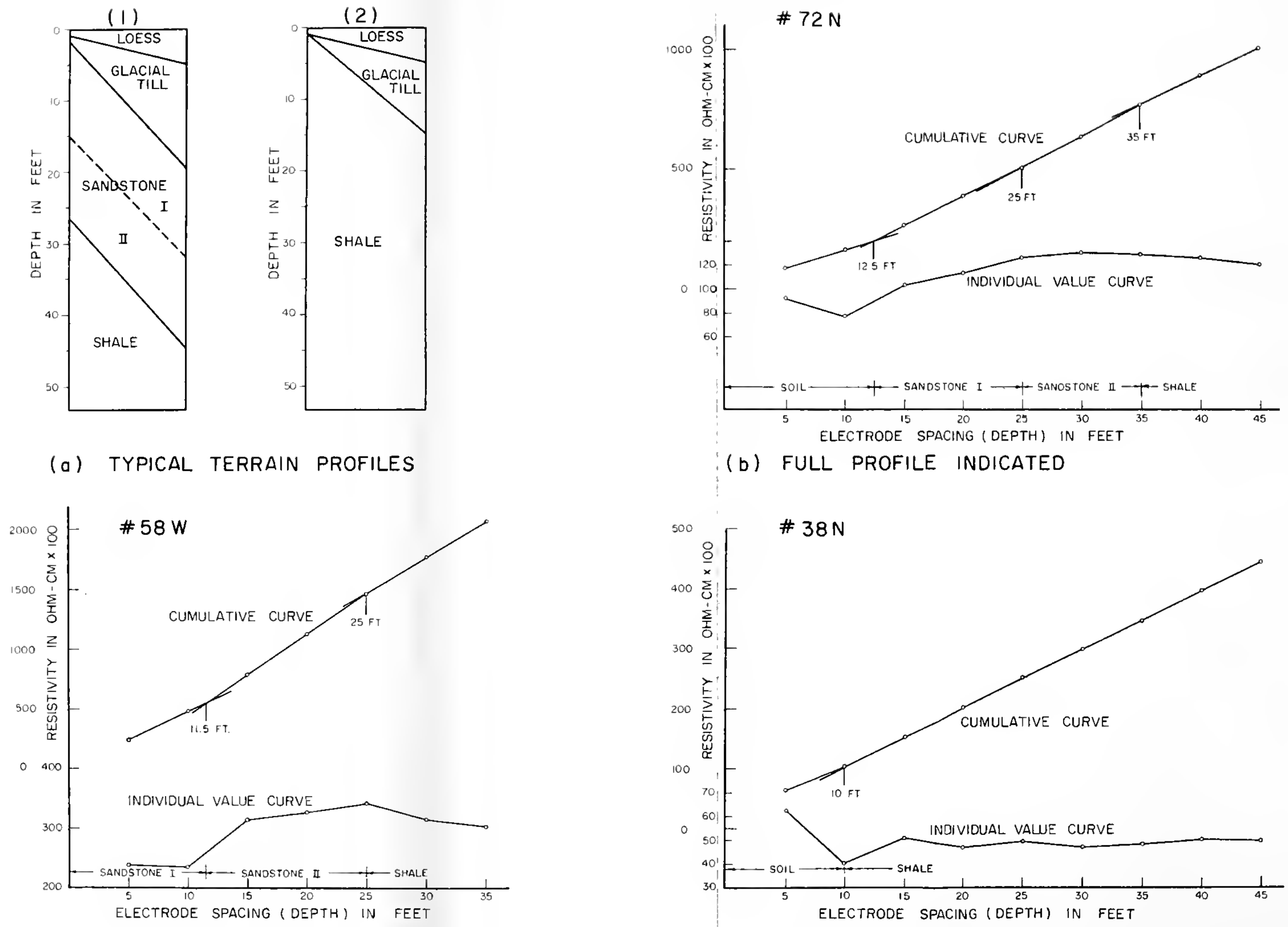


INDICATED



ERLAIN BY SHALES

SITE III.



(a) TYPICAL TERRAIN PROFILES

(b) FULL PROFILE INDICATED

(c) SHALLOW TO SANDSTONE

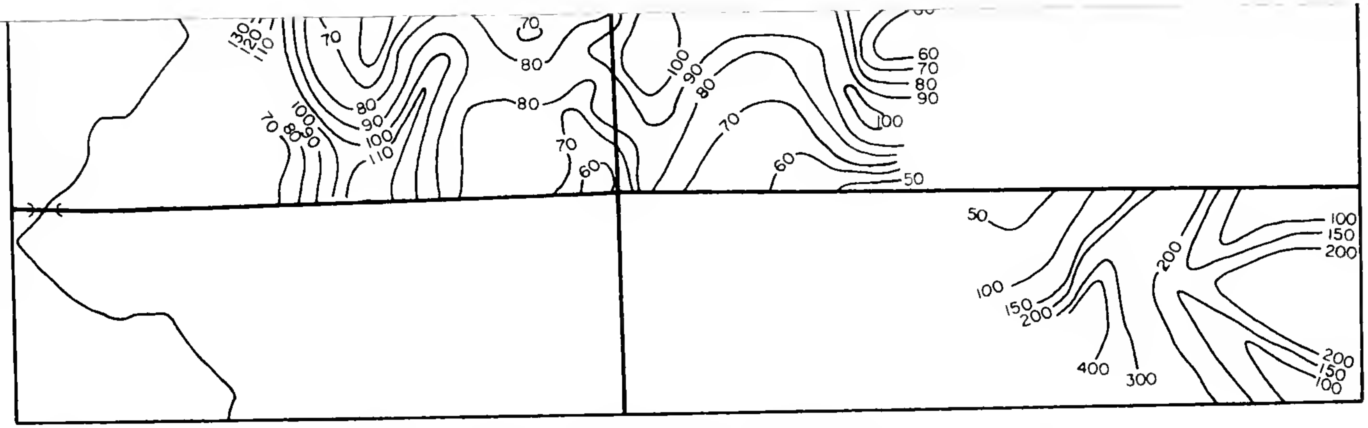
(d) DIRECTLY UNDERLAIN BY SHALES

FIGURE 47. TYPICAL TERRAIN PROFILES AND RESISTIVITY CURVES FOR SITE III.

Distinct breaks are noted at the soil rock interface, within the sandstone layer and at the sandstone-shale interface (noted by a decrease in resistivity values). These breaks are denoted at the bottom of the graph. The break shown within the sandstone layer may be due either to a transition between weathered and unweathered sandstone, or to a transition between thinly bedded and more massive bedded sandstones or possibly to both. Both conditions have been noted in field inspections. Figure 47c shows the change from the typical curve that occurs when the sandstone bedrock is near the surface. In such cases, the resistivity values obtained are much higher to begin with and normally increase with depth until shales are encountered. Figure 47d shows the change in the form of the resistivity curve obtained when the condition represented in profile 2 is encountered. Under these conditions, the resistivity readings are low and remain low as the depth of investigation is increased. A variation on this last pattern is obtained for the condition when the shale is close to the surface. In this case the resistivity value is high to begin with but decreases in value as depth of investigation is increased. The high initial readings are caused by the poor contact obtained between the electrodes and the bouldery surface soil. The resistivity data for points 31 and 32 demonstrate this case (Table A.2, Appendix A).

An analysis of the data obtained demonstrates the value of resistivity surveys in obtaining valuable information on soil and rock conditions. An indication of the type of information that can be developed is shown in Figure 48.

The depth to bedrock, or the soil-rock interface as interpreted from the resistivity logs for the surveyed areas is shown in Figure 48a. The dashed lines indicate the expected trend for unsurveyed areas. A

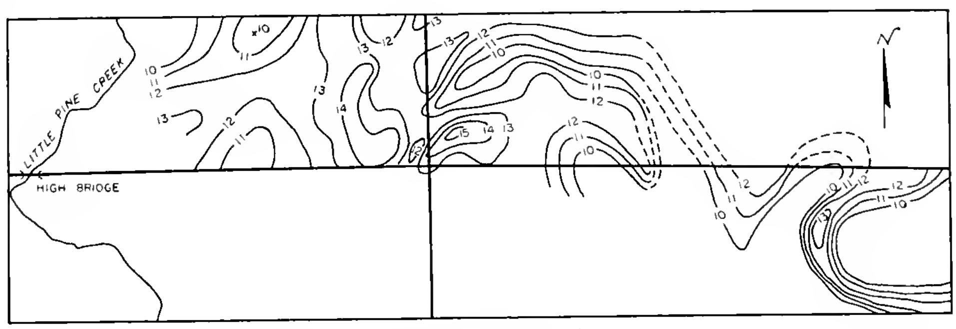


(d) 15 FOOT RESISTIVITY CONTOURS

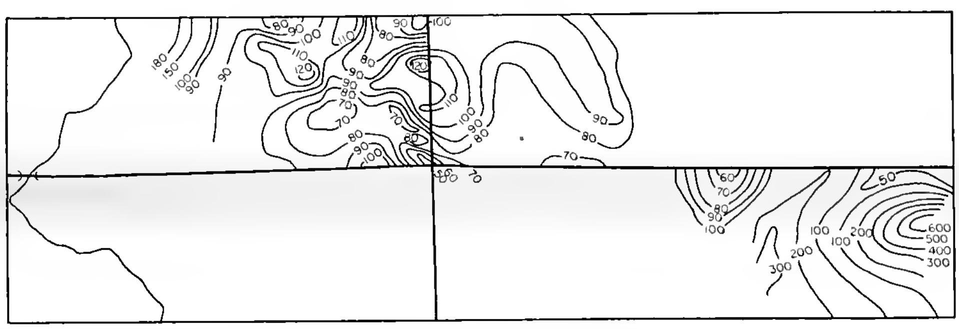
NOTE: ALL RESISTIVITY CONTOURS ARE OHM - CM x 100

SCALE APPROXIMATELY 1 : 15,840

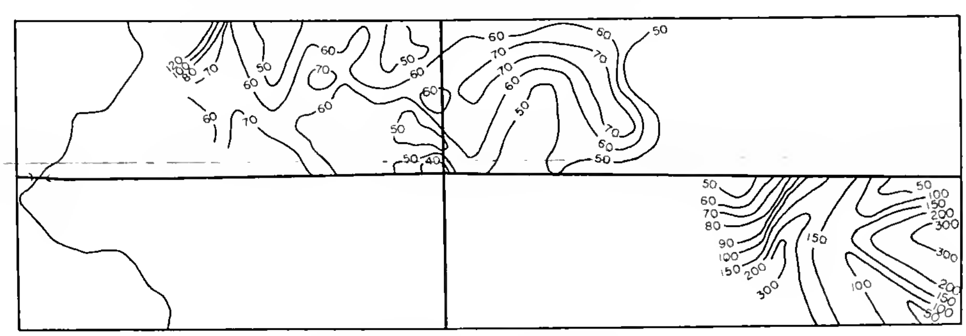
FIGURE 48. INTERPRETIVE MAPS DEVELOPED FROM RESISTIVITY DATA.



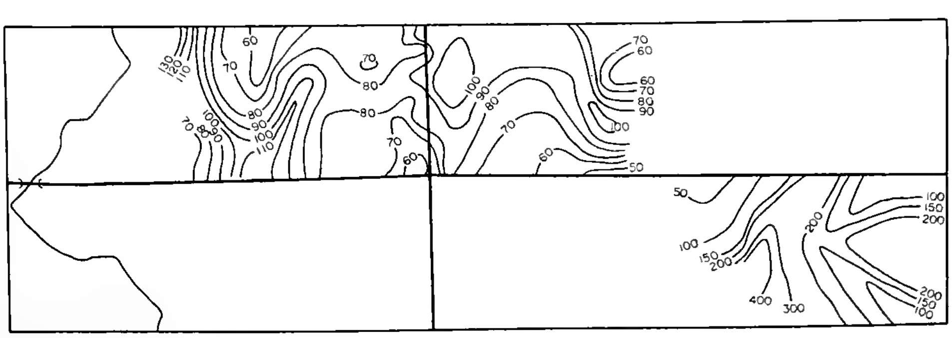
(a) DEPTH TO BEDROCK (FEET)



(b) 5 FOOT RESISTIVITY CONTOURS



(c) 10 FOOT RESISTIVITY CONTOURS



(d) 15 FOOT RESISTIVITY CONTOURS

NOTE: ALL RESISTIVITY CONTOURS ARE OHM – CM × 100

SCALE APPROXIMATELY 1 : 15,840

FIGURE 48. INTERPRETIVE MAPS DEVELOPED FROM RESISTIVITY DATA.

comparison of this map with the resistivity contour map provides information about the soils and rock types to be encountered.

A comparison of the five foot resistivity contour map (Figure 48b) with the bedrock map (Figure 48a) indicates some interesting features. It has been noted in Figure 47 that areas with bedrock at or close to the surface are characterized by very high resistivity readings. Thus, one may readily identify the areas with shallow bedrock, such as the one in the southeast quadrant of the map and the one in the northwestern part of the map. Comparisons of the soil profiles and resistivity readings revealed the following: (1) areas with shallow bedrock had the highest readings (generally greater than 20,000 ohm - cm.); (2) areas with granular materials were found to have readings about 11,000 to 12,000 ohm-cm.; (3) areas with thick loess cover (4 to 5 feet) had resistivity readings about 10,000 ohm - cm.; and (4) where the loess cover was thin, lower readings were obtained as the resistivity values were influenced to a greater extent by the underlying glacial tills which have low resistance (4,000 to 5,000 ohm - cm.). Thus the five foot resistivity contour map can be used as a guide for the separation of surface soil units. Interpretations of this type, however, must be used with caution and field checks should be made to confirm them. Certain factors such as a high water table, buried conductors or unaccounted for changes in subsurface conditions can change these relationships and cause errors in the interpretation of the data. Resistivity literature contains ample discussion of these interpretation problems.

The ten foot resistivity contour map, Figure 48c, shows the influence of the glacial tills on the resistivity readings. The low resistance of

the glacial tills tends to mask the differences in the soil profile (except in the regions of shallow bedrock previously indicated). Very little difference in readings is noted at this level (4,000 to 7,000 ohm - cm.) as compared to what was encountered at the five foot level (5,000 to 12,000 ohm - cm.). By comparing Figure 48c to 48a, the trends in the bedrock surfaces are observed. Some of the "70" contour lines correspond to the 10 foot and 11 foot bedrock contours of the sandstone. Although trends in the shale are also present, they can not be positively separated from the till because of low readings.

The fifteen foot contour map, Figure 48d, agrees fairly well with the depth to bedrock map. The high bedrock surfaces are indicated either by high readings (greater than 10,000 ohm - cm.) over the sandstones or by low readings (6,000 ohm - cm or less) over the shales. This latter case illustrates the danger inherent in the interpretation of resistivity data without adequate control. From the limited borings available in the area one might have assumed that the low resistivity readings over the high shale bedrock areas were just thicker deposits of glacial till and that the break in the curve indicated changes in till layers.

Ground Truth

The collection of data at the time of flights has become an important factor in multisensor projects. The variety of parameters affecting the photography and imagery require the knowledge of ground conditions at the time of flights in order to evaluate the influence of these parameters on the final tonal patterns obtained. The intent of this phase of the field investigation program was to determine the value of

ground truth data in assisting in the interpretation of the photography and imagery and to determine the types of information that should be measured during the flight.

The amount and types of ground truth data collected in the initial flights were very limited. Initially, only a few moisture measurements were made and color photographs taken to indicate ground conditions. This data was too meager to be of much assistance. The data collected during the last two flight programs (May 2-6, June 1-2) were quite extensive. The evaluation of ground truth measurements with respect to their assistance in interpretation was based on the data from these last flights. Therefore, subsequent discussions will be limited to this data.

The data collected during the last two flights included: (1) surface soil moisture contents; (2) ground color photographs of existing field conditions at sampling sites; (3) field radiometer readings in the 8-14μ band; and (4) meteorological data from local weather stations including temperature, humidity, solar radiation, precipitation, periodic wind velocity, cloud cover and barometric pressure readings. The detailed data for the surface moisture contents and meteorological measurements are included in Appendix A.

Soil Moisture Content Measurements. Soil moisture content determinations were made for the purpose of noting the trends of variation in moisture between selected areas and to see if similar trends could be detected on the aerial photography and imagery. No attempt was made to try to define the "average" moisture contents for the various soils by statistical sampling of the sites or to try to correlate the moisture content values to specific tones on the photography and imagery. The

work of other investigators indicated the futility of attempting this because of the numerous parameters affecting the tones (see discussion on page 94). The aim of this sampling program was to sample as many of the sampling sites as close to the flight times as possible. Many sites were sampled the day following the flights because time, distance and personnel factors prevented concurrent sampling.

Moisture samples (generally one or two), were collected in the topographic highs and lows for a given soil unit. Samples were taken from the top six inches of the surface. An attempt was made to sample the same sites during each flight, but because of crop and vegetation changes during the year, this was not always possible. The sites sampled during the May and June flights and the results obtained are shown in Appendix A, Figures A.2, A.3 and Table A.3 respectively.

Field Radiometer Measurements. The purposes of this phase of the measurement program were:

1. To determine if the various soil and rock units significant to engineering soil mapping had measurable differences in emitted radiant energy in the 8 to 14 micron region;

2. To determine if these energy differences when present could be detected on the imagery;

3. To determine the period during the day when differences in the various soil and rock units were maximum; and

4. To determine if a flight at approximately this time would increase the amount of information obtained.

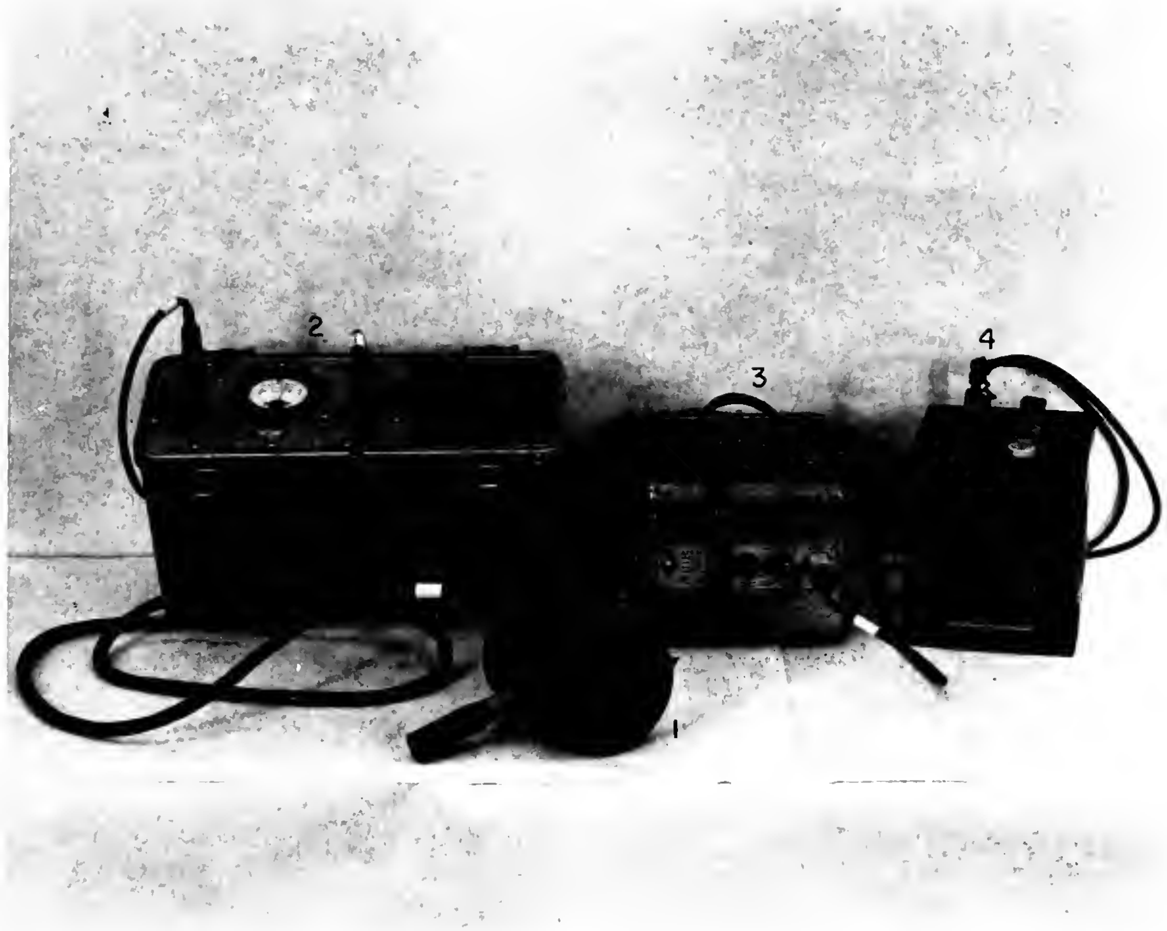
The radiometer used for the field measurements was a portable radiation thermometer (Barnes - Model PRT-4). This instrument operates

in the 8 to 14 micron region and has a detection range from $10^{\circ}F$ to $110^{\circ}F$. The temperature measured is an "apparent" temperature; that is, the temperature of an object assuming the emissivity is unity (a black body). The radiometer and accessory equipment are shown in Figure 49.

To evaluate the various items listed above, a variety of soil and rock units were sampled with the instrument during the flight programs of May and June. In addition, measurements were taken during the period of May 25 to 27, 1966. During the flights, measurements were made as close to the time of the flight as possible. Three to six readings were taken for each site after the instrument stabilized. The measurements were taken vertically and at several different angles.

A summary of the radiometer measurements taken of selected soil and rock units are listed in Table 6. The readings shown are the representative values obtained based on the various scans. These readings were obtained on four different dates between the hours of 11:00 a.m. and 3:00 p.m. The location of the sites where radiometer readings were taken are shown in Appendix A, Figures A.2 and A.3. The table is divided into two main parts; measurements obtained on May 6, and measurements obtained May 26, 27 and June 2. Different sites were sampled on May 6, than were sampled on the other dates. On May 6, measurements were also obtained from the platform of a high ranger truck at an elevation of fifty feet above the ground. To facilitate comparisons the data are grouped according to the various land forms and terrain units sampled in each site.

Although the sampling program and data collected were not of sufficient detail to quantitatively evaluate the various parameters affecting infrared imagery, several trends can be noted. It is apparent



1. RADIOMETER — OPTICAL HEAD
2. METER UNIT AND CARRYING CASE
3. INVERTER
4. 12 VOLT BATTERY

FIGURE 49. RADIOMETER AND ACCESSORY EQUIPMENT FOR FIELD OPERATIONS.

Notes to Table 6

a - Readings shown are average apparent temperature (°F) based on from three to six measurements.
b - Coincided with aerial flight.
c - Time of measurements 1100 to 1230 hrs. in Site II; 1330 to 1500 hrs. in Site III. Aerial Flight from about 1330 to 1430 hrs.
d - Time of measurements 1220 to 1300 hrs. in Site II; 1315 to 1330 hrs. in Site I.
e - Time of measurements 1100 to 1330 hrs. in Site III. Three series of measurements were taken during this period.
f - Time of measurements 1120 to 1150 hrs. in Site III; 1220 to 1320 hrs. in Site II. Aerial Flight from about 1100 to 1230 hrs.
g - Field status indicated are: recent - plowed within recent few weeks; fresh - plowed within few hours of measurements; fall - plowed last fall and not since. When no comment shown for plowed field it indicates field plowed in Spring but not within recent weeks.
h - Intergrade soils are transitional between Forest and Prairie Soils. Both vegetation conditions existed in this zone.
i - Higher readings were obtained when radiometer between 45-90°; lower readings when less than 30°. From closer analysis of photo coverage of a site, higher readings may reflect measurement of a depressional soil area instead of upland area.
j - Other upland soils have a loess cover and a lighter color while this soil has upper loess horizon eroded off and a more reddish brown color.
k - On ground, measuring small area of shallow soil 6-12 inches thick over bedrock. From air, including other features such as vegetation in the reading.
l - Measurement of local area of coarse gravel, 2-3 inches in size.

erent Dates

		May 27, 1966[e]		June 2, 1966[b,f]	
Site	Soil	Field Status	Ground	Field Status	Ground
			°F		°F
I.	San	--	--	--	--
	Gra	--	--	--	--
II.	Gla				
		--	--	--	102
		--	--	--	106
		--	--	--	--
		--	--	--	110+
		--	--	--	--
		--	--	--	--
		--	--	--	--
		--	--	--	--
		--	--	wheat	70,68
		--	--	fresh	104
		--	--	recent	107
		--	--	recent	110
		--	--	--	90
	Gra	--	--	--	105
	Gra	--	--	--	--
	Res	--		--	110+
III.	Gla				
		--		--	--
		--	100, 110+, 109	--	100
		--	110+, 110+, 110+	--	110+
		--	--	--	--
		--	--	--	--
		--	--	--	--
		--	--	--	--
		--	--	--	--
		--	86, 87, 91	--	94
		--	--	--	--
		--	--	--	--
	Sand	--	97, 99, 102	--	104
	Shal	--	110, 110, 110+	--	110+
	Floo		85, 85, 86	--	88
	Grav	--	--	--	--
		--	--	--	--
		--	--	--	--
	Stre	--	70, 72, 72	--	63

Notes to Table 6

a - Readings shown are average apparent temperature (^{o}F) based on from three to six measurements.

b - Coincided with aerial flight.

c - Time of measurements 1100 to 1230 hrs. in Site II; 1330 to 1500 hrs. in Site III. Aerial Flight from about 1330 to 1430 hrs.

d - Time of measurements 1220 to 1300 hrs. in Site II; 1315 to 1330 hrs. in Site I.

e - Time of measurements 1100 to 1330 hrs. in Site III. Three series of measurements were taken during this period.

f - Time of measurements 1120 to 1150 hrs. in Site III; 1220 to 1320 hrs. in Site II. Aerial Flight from about 1100 to 1230 hrs.

g - Field status indicated are: recent - plowed within recent few weeks; fresh - plowed within few hours of measurements; fall - plowed last fall and not since. When no comment shown for plowed field it indicates field plowed in Spring but not within recent weeks.

h - Intergrade soils are transitional between Forest and Prairie Soils. Both vegetation conditions existed in this zone.

i - Higher readings were obtained when radiometer between 45-90^{o}; lower readings when less than 30^{o}. From closer analysis of photo coverage of a site, higher readings may reflect measurement of a depressional soil area instead of upland area.

j - Other upland soils have a loess cover and a lighter color while this soil has upper loess horizon eroded off and a more reddish brown color.

k - On ground, measuring small area of shallow soil 6-12 inches thick over bedrock. From air, including other features such as vegetation in the reading.

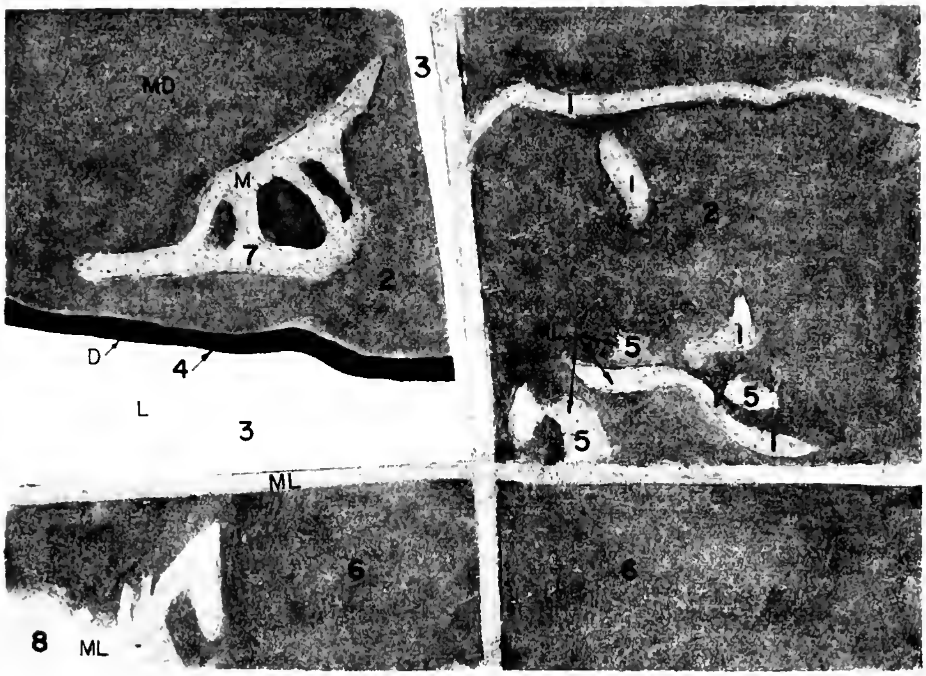
l - Measurement of local area of coarse gravel, 2-3 inches in size.

Table 6. Radiometer Measurements for Selected Soil and Rock Units - Comparison at Different Dates

Site	Soil or Rock Unit			Radiometer Readings[a] May 6, 1966[b,c] Sample Point	Field Status[g]	Ground °F	50 Feet Altitude °F	May 26,1966[d] Sample Point	Field Status	Ground °F	May 27, 1966[e] Field Status	Ground °F	June 2, 1966[b,f] Field Status	Ground °F
I.	Sand Dunes			--	--	--	--	10	--	110+	--	--	--	--
	Gravel Deposits in Pit			--	--	--	--	11	--	106	--	--	--	--
II.	Glacial Till													
	A. Prairie	Highs	- plowed	A3	recent	--	80	2	--	110	--	--	--	102
			plowed	--	--	--	--	4	--	110+	--	--	--	106
		Depressions	plowed	A4	fresh	92	91	--	--	--	--	--	--	--
			plowed	A2	fresh	--	91	3	--	110+	--	--	--	110+
			plowed	B1	fall	86	89	--	--	--	--	--	--	--
			plowed	B2	fall	86	87	--	--	--	--	--	--	--
			stubble	B3	--	80	79	--	--	--	--	--	--	--
			stubble(plowed)	B4	fresh	59	60	--	--	--	--	--	--	--
			vegetation	A1	oats	81	82	--	--	--	--	--	wheat	70,68
	B. Intergrade[h]	Highs	plowed	--	--	--	--	1	fall	94	--	--	fresh	104
	C. Forest	Highs	plowed	--	--	--	--	5	recent	105	--	--	recent	107
			plowed	--	--	--	--	8	recent	110+	--	--	recent	110
		Depressions	plowed	--	--	--	--	7	--	86	--	--	--	90
	Gravel Deposits in Pit			--	--	--	--	6	--	106	--	--	--	105
	Gravel Road			A7	--	89	86	--	--	--	--	--	--	--
	Residual Shale Fragments/Shale			--	--	--	--	9	--	110+	--		--	110+
III.	Glacial Till													
	Forest	Highs	plowed	D1	fresh	89	86	--	--	--	--		--	--
			plowed	D2	recent	90(79)[i]	72	14	--	--	--	100, 110+, 109	--	100
			plowed	D5	--	--	78	13	--	--	--	110+, 110+, 110+	--	110+
			plowed	F5	--	77	75	--	--	--	--	--	--	--
		(soil color change)[j]	plowed	F4	--	94	94	--	--	--	--	--	--	--
		(shallow to bedrock)[k]	plowed	F2	--	93	81	--	--	--	--	--	--	--
			vegetation	E3	oats	--	78	--	--	--	--	--	--	--
			vegetation	E7	pasture	--	76	--	--	--	--	--	--	--
		Depressions	plowed	F1	recent	91	91	16	--	--	--	86, 87, 91	--	94
			plowed	F2	--	--	99	--	--	--	--	--	--	--
			vegetation	F3	pasture	--	80	--	--	--	--	--	--	--
	Sandstone Outcrop			E1	--	91	92	15	--	--	--	97, 99, 102	--	104
	Shale Outcrop			--	--	--	--	17	--	--	--	110, 110, 110+	--	110+
	Flood Plain, Shallow Over Shale			--	--			18	--			85, 85, 86	--	88
	Gravel Road			D4	--	92(96)[l]	89	--	--	--	--	--	--	--
				E4	--	--	92	--	--	--	--	--	--	--
				F6	--	99	95	--	--	--	--	--	--	--
	Stream			--	--	--	--	19	--	--	--	70, 72, 72	--	63

that the differences due to farming practices and vegetative cover cause as much or more variation in the effective temperatures recorded than do differences in type of soil or rock. This is best shown in the variation of readings obtained on May 6th. Differences are noted among readings for fields freshly plowed, those plowed within a week or so of the field study, those plowed in the Fall of 1965, and those left in stubble. The largest variation noted, was between a freshly plowed stubble field and all other field conditions. Thus, land use has a direct influence on the effective temperature recorded. Also, it is evident that the presence of vegetation of any type (old stubble fields, pasture, or fields with oats barely six inches high), resulted in low radiometer readings. Therefore, other things being equal, vegetation in this region should give relatively dark tones on daytime infrared imagery in the 8 to 14 micron band. This trend was noted on the imagery.

A study of the values obtained for the various soil and rock units delineated indicates that some differences between these units can be observed; however, consistent trends are not always apparent. For example, most of the average apparent temperature readings obtained on May 6 for glacial till highs (prairie and forest) are lower than corresponding readings obtained for the glacial till-depression soils. Thus on infrared imagery of this data, the high till soils should appear darker on the imagery than the depression soils. This trend is seen in Figure 50 which is an "artist sketch" of "classified" infrared imagery in the 8 to 14 micron band obtained over Site III on May 6, 1966. Some exceptions to this trend, as noted by higher temperature readings for high till soils, are due to fresh plowing of the soil and to the darker



LEGEND:

1. PLOWED FIELD-DEPRESSION
2. PLOWED FIELD-HIGHS
3. RECENTLY PLOWED FIELD
4. PLOWING IN PROGRESS
5. PLOWED FIELD-HIGHS (DARK COLORED SOILS)
6. PASTURE FIELDS
7. UNDERLAIN BY DRAINAGE TILES
8. ERODED SOILS

TONES:

L LIGHT
ML MEDIUM LIGHT
M MEDIUM
MD MEDIUM DARK
D DARK

(NOTE: LAND FORM IS GROUND MORAINE)

FIGURE 50. "ARTIST SKETCH" OF INFRARED IMAGERY FOR PORTION OF SITE III.

color of the soil (e.g., D1, F4, Table 6). As expected these areas appear lighter on the imagery (refer to points 3 and 5 respectively on Figure 50). Other tonal features related to different farming practices (e.g., plowing, drainage tiles), soils, or vegetation are indicated. This area depicts one land form - ground moraine, yet five different tonal patterns are distinct on the imagery due to the various features. This sketch illustrates the difficulty encountered in interpreting the imagery without any ground truth or other information available.

The trend of the glacial till-high soils having lower recorded apparent temperatures than the glacial till-depression soils was not consistently or clearly indicated in the data collected on the other dates. In some cases, as for example in the prairie soils, there was little difference between the highs and depressions. In contrast, for forest soils in Sites II and III, the highs had higher readings than the depressions. Although apparently unexplainable from the limited data obtained in the field measurements, an analysis of the photography and imagery obtained indicated that the depressions were cooler (darker on the imagery) in the areas sampled because they had higher moisture contents. Where the depressions were dry, they had a slightly lighter tone on the imagery than the high soil areas following the usual trend.

Other trends noted with respect to the various soil and rock units indicate that exposed shales and shale fragments as well as sand dunes should have light tones on the imagery, while sandstones although light, should appear slightly darker. The ability to separate these units from glacial till would depend on the time of year, or soil conditions (e.g., dry, wet, moist) encountered at the time of measurements. It also

appears that gravel roads and gravelly material will be light, but not as light as sand dunes. Streams should appear the darkest on the daytime imagery.

A comparison of the measurements made on the ground, to those taken from fifty feet in the air on May 6 show the readings are similar for most points. The differences in readings obtained for a few points (e.g., D2 and F2) are due to differences in the areas scanned from each location. A smaller area is scanned on the ground than from the higher measuring point. Therefore, if the area scanned is not uniform, the particular area scanned on the ground may not be representative of that viewed from the air and thus differences in readingsmay result. This could be a critical factor in choosing ground stations in order to predict tonal patterns that will be obtained from the air.

Intermittent field measurements were taken over a three day period at Sites II and III to evaluate the usefulness of field radiometer measurements for determining the period of the day when differences between the various soil and rock units were maximum. Since visible photography was considered a very important part of the multisensor system and would have an influence on the time of day concurrent imagery would be obtained, readings during the daytime were limited to the hours considered optimum for visible aerial photography, especially color (i.e., 1100 to 1300 hours). During the night, readings were taken during the periods of maximum change; i.e., from a period just prior to sunset or sunrise to a few hours past for each. This effort was made to determine whether differences could be seen between the various soil and rock units based on their physical properties (e.g., specific heat,

thermal conductivity). During these periods, the rate of change of the surface heat balance between the sky and the terrain is greatest. Therefore, differences in rate of cooling or heating due to the physical properties of a material might aid in its identification.

Readings were first taken at Site II. Based on these readings it was decided that at this time of year (spring) measurements taken before sunrise would not be suitable because of the presence of heavy dew which obliterated differences between most of the materials sampled. Therefore, measurements at Site III were taken only during the periods of noon and sunset.

Table 7 lists the values obtained during these measurement periods for the various soil and rock units. In this table, the units (shown by symbols) are listed in a ranking order from the highest apparent temperature obtained to the lowest. The data included are the measurements obtained during the three day period of May 25 to 27, 1966 and during the June 1-2 flights. Measurements were made at the same sampling points during both recording periods. The status of some of the fields at the various sampling points are noted at the bottom of the table.

In analyzing the data, two major trends are evident which can be valuable in separating and mapping the various units shown. The first major trend indicated is that at some time during the measurement program, there was a reversal in the ranking of the various units. This would indicate that tonal reversals (i.e., the lighter soil unit became darker and vice versa) could be obtained between various units of interest if imagery were acquired at the correct times. For example, in the comparison of soil units D and E a reversal of tones is indicated as occurring

ly Variation

ɔ Lowest[a]		
	June 1[b]	June 2[b]
1230	2245-2315	1215-1315
I-110+	A-50	B-110+
G-110+	E-49	I-110+
D-110+	I-49	G-105
A-110+	G-47	D-104
B-110+	C-47	C-104
C-94	D-46	A-102
E-86	B-44	E-90
--	L-44	L-70
	June 1	June 2
1330	2130-2200	1115-1145
F-110+	K-63	F-110+
I-110+	J-56	I-110+
D-110+	E-56	D-100
H-104	H-56	E-94
E-89	F-52	H-92
J-86	D-52	J-88
K-72	I-51	K-63

e and Field Status

Site III	May	June
--	--	--
--	--	--
--	--	--
14	(recent)	--
16	(wet)	(dry)
13	(recent)	--
--	--	--
15	--	--
17	--	--
18	(recent)	veg.
19	--	--
--	--	--

fall and not since.
hours of measurements.
ent few weeks.

Table 7. Radiometer Measurements for Selected Soil and Rock Units - Daily Variation

Radiometer Readings - Ranking Order Highest Effective Temperatures to Lowest[a]															
Date		May 25, 1966								May 26, 1966					June 1[b]	June 2[b]
Site	Time	1900	1930	2000	2030	2100	2130	2200	2230	0430	0500	0530	0600	1230	2245-2315	1215-1315
II		G-80[c] 73	G-71	G-67	G-64	G-62	G-60	G-59	--	E-53	E-52	B-51	B-53	I-110+	A-50	B-110+
		D-73	D-67	A-65	A-62	A-61	A-59	A-57	--	G-50	G-49	A-49	A-52	G-110+	E-49	I-110+
		A-68	A-67	D-62	E-59	E-59	E-58	E-57	--	I-48	B-49	I-49	I-52	D-110+	I-49	G-105
		B-68	B-64	I-62	I-58	C-56	B-56	B-56	--	A-47	I-48	G-48	G-51	A-110+	G-47	D-104
		E-65	I-63	E-58	C-54	I-55	C-55	D-55	--	B-44	A-48	E-48	E-51	B-110+	C-47	C-104
		I-63	E-61	B-57	B-54	B-55	1-55	I-54	--	C-43	C-41	C-45	C-50	C-94	D-46	A-102
		C-63	C-58	C-53	D-52	D-53	D-55	C-51	--	D-39	D-39	D-38	D-46	E-86	B-44	E-90
		--	--	--	--	--	--	--	--	--	--	--	--	--	L-44	L-70
Date		May 26, 1966								May 27, 1966					June 1	June 2
Site	Time	1900	1930	2000	2030	2100	2130	2200	2230	1130	1200	1230	1300	1330	2130-2200	1115-1145
III		F-79	F-73	K-71	K-71	K-71	K-70	K-70	K-70	F-110+	F-110+	F-110+	F-110+	F-110+	K-63	F-110+
		D-77	D-71	F-69	E-68	E-66	E-65	E-64	E-64	I-110+	I-110+	I-110+	I-110+	I-110+	J-56	I-110+
		I-77	I-71	E-69	H-66	D-66	D-64	D-60	D-62	H-97	D-106	D-110+	D-110+	D-110+	E-56	D-100
		H-73	K-71	H-66	J-64	H-65	J-62	H-60	H-60	D-93	H-98	H-99	H-102	H-104	H-56	E-94
		J-73	E-69	D-65	I-62	J-63	I-61	J-60	J-59	E-86	E-86	E-87	E-88	E-89	F-52	H-92
		K-71	J-69	J-65	D-59	I-61	H-60	I-59	F-57	J-85	J-85	J-85	J-85	J-86	D-52	J-88
		E-68	H-67	I-63	F-57	F-57	F-57	F-59	I-55	K-70	K-71	K-72	K-72	K-72	I-51	K-63

Unit		Soil and Rock Units	Sampling Site and Field Status					
			Site II	May	June	Site III	May	June
A	-	Glacial Till (prairie) - Highs	2,4	--	--	--	--	--
B	-	Glacial Till (prairie) - Depression	3	--	(recent)[f]	--	--	--
C	-	Glacial Till (intergrade) - Highs	1	(fall)[d]	(recent)	--	--	--
D	-	Glacial Till (forest) - Highs	5,8	(fresh)[e]	(recent)	14	(recent)	--
E	-	Glacial Till (forest) - Depression	7	--	--	16	(wet)	(dry)
F	-	Loess over Glacial Till (forest) - 4-5 ft. thick	--	--	--	13	(recent)	--
G	-	Sand and Gravel - Gravel Pit	5	--	--	--	--	--
H	-	Sandstone	--	--	--	15	--	--
I	-	Shale	9	(fresh)	(recent)	17	--	--
J	-	Flood Plain Deposits Over Shale	--	--	--	18	(recent)	veg.
K	-	Water (Little Pine Creek)	--	--	--	19	--	--
L	-	Vegetation (winter wheat)	1A,2A,6A	--	veg.5-6'tall	--	--	--

a - Values interpolated from data plotted on graph.
b - Only one series of readings taken during flights. Time period indicated to nearest quarter of an hour.
c - Higher readings obtained in sunlight, lower in shade.
d - Field plowed last fall and not since.
e - Plowed within few hours of measurements.
f - Plowed within recent few weeks.

between 1930 and 2030 hours at both sites. From this time period until a short time after 0600 hours, the data demonstrates that soil unit É should appear lighter than the soil unit D on imagery taken during this period. At other times, the reverse is noted.

Another possibility indicated by this trend is that of increasing the chance of interpreting or differentiating soil units of interest by obtaining the imagery when there is a maximum difference in effective temperature between the units. The June infrared flight was planned for this purpose; to see if an evening flight would increase the ability to differentiate the various soil and rock units in the test areas above that obtained by day flights. Based on the data obtained from the field measurements on May 25-27, it was decided that the maximum contrast between most of the units would be obtained by an evening flight from sunset to about 2000-2100 hours. After that, the readings indicated the differences in temperature became too small to clearly differentiate most of the soil and rock units.

The second major feature noted was that the various trends and tonal relationships obtained during the May sampling program were repeated in the June sampling program even though the actual values were not the same. For example, the trends indicated for the soil units D and E in both sites II and III showed that the same tonal relationship existed between these soil units in June as had existed in May. These comparisons demonstrate the possibility of using field radiometer readings to predict the tonal patterns that would be present in a given area and to plan infrared flights at times of maximum contrast.

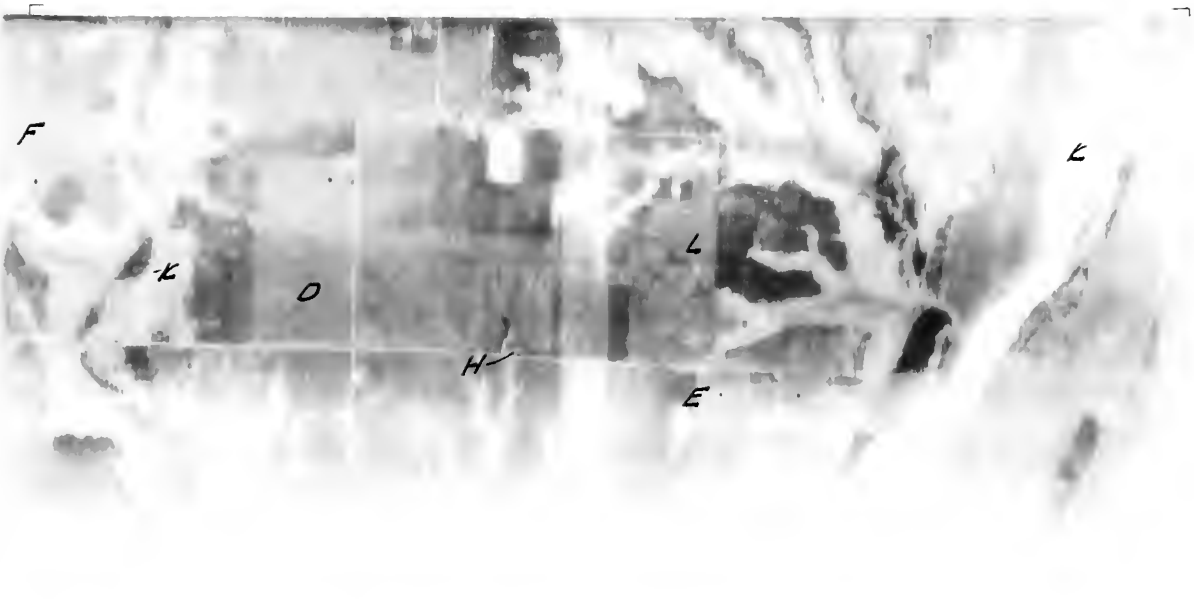
An additional feature evident from the data in Table 7 is that the

major water areas remained at a fairly constant temperature during the measuring period. This indicates the possibility of obtaining a general idea of the range in temperature change for a material of interest by comparing its tones to that of water.

To demonstrate the applicability of the use of field measurements to predict tonal patterns on imagery and to indicate some of their limitations, infrared imagery obtained during the June 1-2 flights are included. Figure 51 contains both daytime and nighttime "declassified" 8-14 micron imagery obtained over a portion of Site III. The imagery is somewhat degraded from the original negative so that some of the subtle differences are not as apparent.

Several of the trends indicated by the field radiometer readings can be seen on the imagery. On the nighttime imagery, the water, K is the lightest tone, followed in decreasing order by the units H, E, then D and F (refer to Table 7 for description of units). The darkest tones are due to winter wheat or tall grass, L. Except for the sandstone, H, the others are approximately in the order indicated by the field readings. However, there is very little difference apparent on the imagery between the last three units. Similar comparative trends are noticed on the day-time imagery. The lightest tone is imaged by F followed by H, E, D, and K. Tall vegetation and trees, L are almost as dark as the water. In this case also, the trends indicated by the field measurements (except for the sandstone H, and glacial till depression units E) appear to be in the proper ratios.

Although many of the tonal relationships found on the imagery agree with the field readings, the discrepancies indicate some of the major



(a) NIGHTTIME - 2056 HRS. JUNE 1

(b) DAYTIME - 1112 HRS. JUNE 2

FIGURE 51. "DECLASSIFIED" 8-14μ INFRARED IMAGERY FOR SITE III.

limitations encountered in trying to predict relative tonal patterns on the imagery from readings on the ground. First, as noted from Table 6 the effective area scanned on the ground is much smaller than that scanned from the air. Therefore, if the area sampled on the ground is not representative for a relatively large and uniform area, the relative tones obtained on the imagery can be different from that expected. This is the reason for the variation that occurred in units H and E. Both of these points were very small in extent and therefore were not representative. The unit E was a small wet depression and if large enough to be seen, would have appeared dark. The dry glacial till-drepressions (E) appear light on both daytime and nighttime imagery.

A second major factor is that the setting of the dynamic range on the instrument during scanning operations can cause differences noted on the ground to disappear on the imagery. This may be the reason for the difficulty in clearly separating the units E, D and F on the nighttime imagery. The dynamic range was probably set to scan the range between the water at the high end and vegetation at the low end. Setting the dynamic range for this large temperature differential, made it difficult to distinguish between some of the units of interest which were only a few degrees apart.

Another major cause of differences is due to land use factors. This was demonstrated with respect to Figure 51. This factor was not a noticeable factor for the areas sampled in the June flight.

The field radiometer measurements have demonstrated that many tonal relationships present on the imagery for various soil and rock units can be predicted from the field measurements. However, to be able to predict

and identify more of the tonal patterns and trends, other data such as moisture content, land use factors (especially with respect to farming practices and vegetative cover) and metereological data are necessary. With sufficient support data, many of the anomalies discovered on the imagery can be explained. It has been determined that many of the patterns on the imagery, unexplainable from limited field measurements and supporting data can be identified by the analysis of the imagery in conjunction with the analysis of other sensor data. This factor will be demonstrated in the next chapter on "Qualitative Interpretation of Photography and Imagery."

CHAPTER 5

QUALITATIVE INTERPRETATION OF PHOTOGRAPHY AND IMAGERY

Introduction

The qualitative analysis of the data collected for the determination of an optimum system was based on the premise that an optimum system would be one which had the greatest potential for evaluating the pattern elements of form, and tone and texture. The potential of the various film and imagery types studied were evaluated by comparison to black-and-white photography, the standard type heretofore used for soils mapping.

The elements of form, and tone and texture are discussed separately where it is possible to separate these items. The initial discussions and comparisons include specific examples of photography and imagery selected from the voluminous data collected. The examples chosen are those which best illustrate the advantages or limitations of the various film and imagery types evaluated or which demonstrate the effects of various parameters on the interpretation of photography and imagery. Detailed engineering soils maps prepared from the analysis of the various film types and imagery data are also included to demonstrate the actual value of the various film and imagery types in preparing these maps. Finally a discussion is included on the assistance afforded by various field measurements in the qualitative analysis. In the summary to this chapter, the various film and imagery types are discussed individually

and the applications and limitations of each type are indicated. Also included in the summary is a brief discussion of combination systems. Based on these final discussions, an optimum system for the mapping of engineering soils is proposed. This is based on no limitations or restrictions. Alternate systems are also proposed where limitations on equipment and/or security restrictions are prevalent.

To facilitate comparisons between the various examples included in the different figures, all the figures in this chapter have been placed at the end of the chapter (starting on page 298). The color photographs included in the report were obtained by photographing the original color film transparencies on the Richards light table and the color film positives in sunlight using a 35 mm. camera with daylight Kodacolor film. Enlarged color prints were made from the 35 mm. color negatives and the colors adjusted, to match the original prints as close as possible during the printing process.

Analysis of Various Film and Imagery Data - Elements of Tone

The major item studied in the qualitative analysis of the various film and imagery types was the variations in the element of tone. Variations in "texture" on the film and imagery were also noted, but no attempt was made to evaluate this item as texture patterns were difficult to describe without having to indicate how they varied between different film and imagery types.

Listed in Table 3, (page 55) are the major factors which comprise the elements of tone. These are tones due to (1) soils and rocks, (2) culture, and (3) vegetation. Tones due to soils and rocks can be further subdivided into those due to the intrinsic color of the unit and

those due to the composition of the unit. Another factor which affects these factors is the tone due to moisture conditions. In the comparison of the various film and imagery types it has been found convenient to compare not just the major factors, but the others also. Therefore, in all comparisons of the element of tone, the factors considered include:

1. Color of soil and rocks
2. Composition of soil and rocks
3. Moisture condition of soil and rocks
4. Culture
5. Vegetation

The evaluation of these five factors and their effect on the tonal patterns seen on the various film and imagery types offers a means of determining soils and soil conditions. For example if the specific effects of color, culture, vegetation and moisture on the tonal patterns can be evaluated, any other tones would be due to the composition of the material. For the test sites studied, the major contrasts of tones due to cultural features are those due to land use and farming practices.

In evaluating the element of tone, separate comparisons are included between (1) the various film types taken within a short time span (2) photography and imagery taken on different dates, and (3) various multiband, multisensor and multichannel data obtained concurrently. The intent of these comparisons is not only to determine which system or systems are optimum for soils identification and mapping, but also to determine if it is necessary to obtain coverage by all sensor systems simultaneously in order to be able to evaluate soils and soil conditions.

Comparison of Photographic Film Types

Examples of the film types investigated are shown in Figure 52. To simplify the reference to the various film types and prints discussed, the following symbols will be used throughout in lieu of the film name.

Black-and-white photography,	B&W
Black-and-white infrared photography,	B-I
Color transparencies (positives),	C-P
Color negative film,	C-N
Color infrared transparencies (positives),	C-I
Color print made from color negative,	C-P/C-N
Black-and-white print made from color negative,	B&W/C-N

The examples in this figure are from the photography obtained during the period of May 2-6, 1966 over a portion of Site II. The area covered is in the transitional zone between soils developed under prairie grasslands and those developed under tree cover. In field comparisons of these soils (developed from the same parent material), it is observed that the soils derived under prairie conditions have darker intrinsic soil colors and higher organic contents. In analyzing the various film types included in this figure, it is seen that the distinction between soils derived under these different types of vegetative cover can be differentiated on certain film types. This factor is demonstrated by studying the plowed fields in the vicinity of points 1 and 2. These fields expose glacial till soils developed under forest cover and prairie cover respectively. Analyzing these areas on the various film types it is seen that these areas can be readily distinguished from each other on C-P because of the differences in color. The darker colored prairie soils have a darker tone commensurate with the darker color of the natural soil. When comparing these areas in shades of gray on B&W or B-I, these areas can not be positively separated. Although different

tonal patterns are present in these two areas on C-I and C-N, because of the unnatural or false colors, it is difficult to correlate the color differences observed to differences in soil types.

The identification and separation of distinct soils, all developed in glacial till (forest), on the basis that intrinsic color is a soil determinant, is illustrated by the contrasts at 3, 4 and 5. These color changes are more vivid on C-P, C-I and C-N photography and make it possible to separate the three soils. This is not the case on the B&W and B-I film types. On B&W, the tones to the left of points 4 and 5 are similar and could not definitely be distinguished as being due to different soils. On B-I, the differences at the same locations are not always distinct. Also in certain areas, the normally darker tone soils represented by point 3 and the moderate tone soils represented by point 4 have similar tones and can not be distinguished (e.g., compare tones above and to left of point 4). A comparison, point for point demonstrates the advantage of C-P over all other types. On C-P, the different color tones can be related to the different types of bare soil. The darker color of the depression soils is related to the higher organic content in these soils. The difference in colors between the high soil areas, point 4 (7.5-10 YR 7/6)[1] and point 5 (7.5-10 YR 6/4) are related to slope erosion and exposure of the subsoil by recent plowing. Although on other color film types the differences between these soils are evident, they are not as unique and can not be directly related to soil conditions alone. This demonstrates an important item in the interpretation of soils from photography. Simply noticing a tonal difference is not

[1] Color indicated is that of the Munsell System (128) as evaluated by the technique of determining munsell notations by use of a densitometer. This technique is described in chapter 6.

sufficient. One has to be able to correlate the tonal difference to natural objects or conditions which can be identified. The ability to identify and interpret various target materials by their natural color tones on C-P photography demonstrates the value of C-P over C-I, B&W and B-I.

One of the major problems in interpreting B&W photography is determining what factors are causing the tonal patterns. Are the darker tones in fields (as for example those including point 6, Figure 52) due to moisture, soil color, vegetation, or soil composition? This can not always be evaluated on the B&W alone. On B-I, plowing of the field (lower field 6) changes tonal pattern entirely. The light streak across the field is the only portion not recently plowed. The light streaks to the left of upper point 6 indicate the possibility that this light tone is due to vegetation. This is not positive though, as all light tones on B-I are not due to vegetation (e.g., point 8). The factor of vegetation being the cause of the tone change in this case is evident however on C-I and is also apparent on C-P. The presence of the red tone on C-I and greenish tinge on C-P in the fields clearly indicate the influence of vegetation. Both types indicate that the vegetation is not very dense and is new growth.

Highly organic soils are evident on all positive film types by dark tones (above point 7). Points 8, 10 and 11 indicate other soil types and tonal relationships. Point 8 is a high soil area in the prairie glacial till zone, point 10 is a gravel pit area with granular materials exposed and point 11 is an area of glacial till deposits over other deposits. A feature to note in this group is that the granular materials (point 10) are light on all film types except the B-I where it has a

medium tone.

A feature which assists in the identification and delineation of various soils and soil conditions on aerial photography is the contrast between an item and its background. The advantage of color in enhancing contrasts is demonstrated by a comparison of the field including point 9. On the C-P, C-I, and C-N originals studied under magnification, boulders were clearly evident in this field. These same boulders were not as distinct or not even evident under similar magnification on either the B&W or B-I. Patches on the dual lane highway could be observed on the same films under magnification. (These items are not discernible on the small reproductions on Figure 52.)

Two additional items are observed on comparing these various film types. On the B-I film type, many more slight tonal changes are noted in various fields (see areas 1-5) than on the other types. These tonal differences are related to differences in moisture contents. The greater tonal differences in this particular example on the B-I film type may well be due to the difference in dates of coverage of the various film types. The B-I was taken a few days after the others, allowing more chance for the soils to dry. The second item is the comparison of C-P to C-P/C-N. The C-P made from C-N has very similar colors to C-P and is of comparable value for interpreting soils.

The comparison of film types as illustrated in this example (Figure 52) demonstrates some advantages and limitations of specific types. These include:

1. The C-P film appears to be best for the interpretation of soils because of the natural colors which aid in identification, the

greater number of colors that can be distinguished, and the greater contrast of intrinsic color between soils which aid in identification and delineation.

2. The C-I film type is best for separating and identifying areas covered with vegetation because of the reddish color produced by vegetation. Effects of vegetation are evident on B-I by light tones, but not all of the light tones are due to vegetation; therefore, the identification can not be as positive. The contrast between soil types is evident on C-I but because of the false color, the reasons for the different colors and tones can not always be determined.

3. Tonal differences are noted on B&W and B-I, but the reason for the tonal differences can not always be determined. Therefore, the differentiation of the various soils was not always possible. In addition, some of the soils which could be separated on C-P due to color differences could not be separated on B&W or B-I because different colors appeared in the same tones of gray.

Comparison of Infrared Imagery and Aerial Photography

The discussion in Chapter 4 indicated that tonal differences present on aerial infrared imagery are related to field radiometer measurements of soil and rock areas. The discussion in this chapter attempts to demonstrate that many of the tonal differences present on the aerial infrared imagery can also be related to soils and soil conditions interpreted from aerial photography. In addition, the discussion includes supplementary or confirming evidence that infrared imagery contributes to the interpretation of soils and soil conditions from the aerial photography.

Comparisons of infrared imagery in two bands (4.5-5.5μ and 8-14μ) and aerial B&W photography are shown in Figure 53. Comparisons of daytime and nighttime imagery in the 8-14μ band are included in Figure 54.

The visible photography included in Figure 53 was taken a month earlier than the infrared imagery. Therefore, some differences in tone may be due to changes in vegetation, moisture conditions or farm practices during the interim. However, the tonal relationships noted for most of the points selected remain relatively unchanged.

Comparing the 8-14μ band imagery and the visible photography, several tonal relationships are present which are of assistance in separating significant engineering soils and rock units. An example is the tonal relationships of points 5 and 6, Figure 53. These represent high areas and depressional areas in glacial tills respectively. As noted on the visible photography, the high areas exhibit light tones while the low areas show relatively dark tones. These tones are reversed respectively on the imagery. The tonal relationships are related to the composition of the materials. The depressional areas (point 6) are high in organic matter, are finer textured and are darker colored soils. The high areas (point 5) are less organic, contain more silts and are lighter colored soils. These relationships result in the high soil areas being lighter on the visible, while the depressional soils are darker. The reversal in the infrared is due to the fact that the darker colored soils absorb more heat than the lighter colored soils and emit more energy in the infrared region.

The occurrence of tonal reversals in the IR related to color differences due to organic content and finer texture are numerous. Another

example is shown by point 1 which is a depressional dark colored, fine textured soil in the flood plains. However, many other factors can change these tonal relationships (see discussion of parameters, page 105). Examples where tonal reversals do not occur for dark, fine textured soils are demonstrated by points 3, 7 and 10. Point 3 is a muck deposit and points 7 and 10 are soils located in low drainage ways in glacial tills. For these soils, the tones are not light on the infrared imagery but medium to dark and for different reasons. The darker tones in areas 3 and 10 are due to a high moisture content while that of point 7 is due to the presence of vegetation. Both of these factors cause a cooling effect on the surface soils thus resulting in darker tones on the imagery.

Similar variations are noted in light colored soils. Not all light colored soils in the visible are dark in the infrared imagery. Many are light or medium light in the infrared. Examples of these are areas denoted by points 2, 4, 8 and parts of 9. Area 2 is sand, area 4 is shale bedrock covered by thin alluvium, point 8 is sandstone bedrock and point 9 is a field where sandstone is very shallow. These areas are light for various reasons (specific heat, thermal conductivity, etc..) which can not be evaluated just by comparison of the infrared imagery and visible photography. However, by comparison of tones present on both systems further separations are possible, for example, area 4 which has medium tones on visible photography can be distinguished from points 2 and 8 which have light tones.

Points 11, 12 and 13 were included to show that in daytime infrared imagery, no differentiation is possible between low vegetation, trees and water.

Comparisons of imagery in the 4.5-5.5μ band and the 8-14μ band indicates that the tonal contrasts seen on the 8-14μ band are in most cases evident on the 4.5-5.5μ band but not as distinct. This is as expected because as indicated in the discussion of basic energy considerations, the peak for the terrain temperatures normally encountered is about 10μ (see page 20). Therefore, maximum emitted energy is recorded in the 8-14μ band.

Daytime imagery in several other bands in the middle infrared (1.5-5.6μ) below the 4.5-5.5μ band was investigated but is not illustrated. The tonal patterns recorded are very similar in appearance to the photographic visible region since solar reflectance and not emitted radiation is sensed. Considering all bands where soils were analyzed, the maximum information was obtained in the 8-14μ band.

Many of the tonal relationships noted in Figure 53 are also present in Figure 54. Comparing the daytime infrared to the visible photography of the same area shown in Figure 52, it is noticed that the dark colored depressional soils (point 3) are lighter on the daytime imagery and the lighter colored high soil areas, (points 4 and 5) are darker on the imagery. In this example, no difference is noted between points 4 and 5 on the imagery. However, in the daytime imagery, obtained in May, differences were noted. Other tonal relationships are evident. Depressional soils on the prairie are light on the imagery (point 2) and high soil areas are dark (point 8). Granular materials in the gravel pit area (point 10) are a medium tone on the imagery while they are light on the visible photography where exposed. Point 11 shows a uniform light tone on the imagery, even though in the visible there are various soil

differences. This change is due to farming practice (recent plowing since visible photography obtained).

Comparison of the daytime to nighttime imagery indicates that certain features are more easily differentiated at night. During the day the tonal difference between low vegetation (point 12), trees (point 13) and water (point 14) are distinguishable on the imagery. At nighttime, the water appears the lightest, the trees are also light but not as light as the water and the low vegetation remains dark. In fact, an indication of drainage ways where water is not flowing can be interpreted from the nighttime imagery (point 15). In this case, the drainage way is dark instead of light.

Differences between soil units, such as those between points 3, and points 4 and 5 are still evident on the nighttime imagery but not as clear. The depressional soil, (point 3) is still the lighter. The granular areas (point 10) have become lighter and more distinct on the nighttime imagery.

The examples discussed demonstrate that infrared imagery can add valuable information to supplement and support the interpretation of various soils and soil conditions from aerial photography. Examples of the tonal relationships observed in Figures 53 and 54 (and 51, chapter 4), for various soils and soil conditions are shown in Table 8.

Table 8. Comparisons of Tonal Relationships in IR and Visible Regions.

Soil or Soil Condition	Visible	IR(daytime)	IR(nighttime)*
Glacial till, depressions (dry)	dark	light	medium light to medium
Glacial till, depressions (wet)	dark	dark	dark
Glacial till, highs	light	dark to medium	medium
Sand dunes	light	light	dark
Sandstone	light	light	medium light
Shale	light to medium	light	medium light
Flood plain, depressions (dry)	dark	light	medium
Organic deposits (dry)	dark	light	**
Organic deposits (wet)	dark	medium to dark	dark
Granular deposits	light	medium to medium light	medium light

* Readings will be a function of time of night imagery obtained.

** Could not evaluate.

Many of the tonal patterns listed in Table 8 have also been observed on daytime imagery at other times of the year. However, other factors, besides moisture, vegetation and farming practices can change these relationships. One such factor is that of the instrument setting at the time of flight. This factor can have a significant effect on the interpretation of the imagery as the ability to separate certain soils depends on the setting of the instrument. Figure 55 shows an "artist sketch" of an area covered by two passes of an infrared sensor within a five minute period. It is seen that many of the tonal differences present on the earlier pass are not evident on the later one and that there is a general shift in tones between similar areas. Certain soils which are significantly different may occur in the same tone on the imagery depending on the instrument setting. This factor also makes it

difficult to attempt to generalize and list typical tonal patterns for various soils.

Comparison of Radar Imagery and Aerial Photography

Radar imagery is developed from an active sensing system; therefore, the frequency utilized and the characteristics of the sensor system greatly influence the amount of useful information on soils that is obtained. All radar imagery obtained during this study utilized K-band frequencies. Consequently, the imagery indicated only the influence of surface conditions.

Figure 56 includes an example of radar imagery illustrating horizontal transmission and receiving (HH polarization) as well as horizontal transmission and vertical receiving (HV polarization) covering sites I and II. The examples shown are enlargements prepared from unclassified "degraded" imagery obtained on September 14, 1965 through thick cloud cover. Visual photography (B&W) of a portion of Site I taken two weeks earlier (September 1, 1965) is included for comparison.

Although the "degrading" and enlarging greatly reduced the resolution of the radar imagery, several major features can still be evaluated, (points 1 through 15, Figure 56). Major topographic breaks (see 1 and 2) are evident on radar. Point 1 indicates the topographic break between the flood plain and terrace and point 2 the break between the terrace and ground moraine (valley wall).

The comparison of the radar imagery obtained by HH polarization to that of HV polarization demonstrates that except for linear oriented objects the only difference noted between the two types is that the HV polarized imagery shows less tonal contrasts than the HH. This is due

to the weaker signal return received for HV systems. For tonal contrasts of linear features such as the airport (point 4), buildings (point 5), roads (point 6) and the railroad (point 7) significant differences are noted. The airport and road systems are less noticeable on HV imagery, while the railroad is more noticeable on this type. Although the return from the buildings is much brighter on the HH, the decrease in return makes the building shapes more distinct on the HV imagery.

In the study of soils and vegetation conditions in this area, it was observed that HH polarized radar is better as an image producing system than HV polarized radar simply because of a stronger signal return which produces more distinct tonal contrasts. Attempts to distinguish different types of soils on the radar imagery were not successful because of the wavelength of radar used. At K-band frequencies, all soils in the test areas are fine-textured in relation to the length of the radar waves and thus specular reflection occurs. The radar signal is reflected away from the radar antenna and all soils appear dark on the imagery and can not be separated from other items that produce specular reflection such as water and roads. The dark tones representing various types of soils are indicated in Figure 56. These include areas of sand dunes (point 8) plowed sandy fields (point 9), sands and gravels in gravel pits (point 10), plowed silty loam surface soils on granular terrace (point 11), and plowed silty clay soils in glacial tills, both highs and depressions (point 12). The lighter tones present on the imagery are due in part to the scatter and return of the signal by various types of vegetative cover. For example, the fields with corn are light as corn exhibits a high return (point 13). Areas covered with trees also show light tones. Pastures and fields with low vegetation have a low (dark)

return (point 14).

Special image tones to note on the figure are the light tones present around the gravel pit areas (point 10) and from the ridges in an old gravel pit (point 3). These returns are not due to texture of the material or presence of vegetation, but to geometric relationships (refer to Figure 28, page 139). Another image of interest is the point marked "a" in the plowed field (point 11). This feature demonstrates how radar assists in the interpretation of B&W photography. On the B&W photograph, point "a" is evidenced as a dark tone which could be interpreted as either due to moisture or vegetation conditions. Because of its low topographic position (a drainage way) and no apparent height on stereoscopic examination, one might conclude that the dark tone on the photograph is due to moisture. However, from a study of the radar imagery, the presence of a light tone indicates that there is vegetation in the channel. If the condition was due to moisture, the tone would be dark on the imagery which is typical for water (point 15). This item caused no problem on the color photography obtained at the same time. On the color photography, a greenish color was present at point "a" indicating the presence of vegetation.

From the example discussed as well as from the evaluation of all radar imagery obtained for this project, it is concluded that K-band radar is of little value for interpreting soils. It is of some value for determining ground conditions (i.e., vegetation, land use). However, the smaller scale and poorer resolution of the radar limit the application to engineering soils studies. The main advantage of radar is that even through heavy clouds, an interpretable image is obtained. This all

weather capability of radar (day or night) has been demonstrated by many investigators.

Comparison of Multiband, Multisensor and Multichannel Data

In the previous sections, comparisons have been made between various types of films, between infrared imagery and visual photography, and between radar imagery and visual photography. These discussions have generally indicated the kind of information obtained from the various types of film and imagery. For most of the examples illustrated, the various types compared were not taken at the same time. The discussion in this section includes examples of systems where the photography and/or imagery are taken simultaneously or concurrently.

Multiband Comparisons. A limited number of nine-lens photographs were taken from the air and from a fifty foot platform during the flight program. The purpose of this phase of the project was to study the tonal relationships of selected sites in several bands of the spectrum from 0.38 to 0.89 microns both from the ground and from the air and to determine whether ground photographs can be used to predict the tonal patterns which will be obtained from the air.

One of the areas studied with the nine-lens camera was a small creek in Site III where sandstone bedrock is exposed. Figure 57 shows the nine exposures obtained from the ground and three aerial exposures. Features of note are the sandstone exposed in the creek (item 2), the presence of a thin silty surface soil over sandstone (item 1) and a vegetated area (item 3). A study of the nine ground exposures (Figure 57a) indicates that these three items can be distinguished clearly only in band 2 and to a lesser degree in band 5. The sandstone is distinct

from the other two features in all bands except 8 and 9 where it appears as light as the vegetation, and band 3 where it appears as light as the silty soil. The soil and vegetation can be separated in bands 2 and 8 and to a lesser degree in band 5. A tonal reversal is evident between these two features in bands 2 and 8. In band 2 the silt is lighter (almost as light as the sandstone) while in band 8 the vegetation is lighter. Band 7 of the nine lens photograph, which is approximately equivalent is normal B&W photography, indicates that on the normal photography the sandstone would be differentiated from the shallow soil and vegetation but that these latter items could not be separated. To differentiate all three features, selective filtering similar to that used for band 2 would be necessary.

Selected bands from the nine-lens aerial photograph of this area demonstrate that the ground photograph adequately predicted the tonal relationships obtained in the same spectral band from the air. Enlarged portions of bands 2, 7 and 8 are shown in Figure 57b. Although the areal extent of the silty soil area is small (item 1) it can be separated from the exposed sandstone (item 2) and the vegetated areas (item 3) in band 2 as predicted from the ground photograph. The tonal relationships noted for bands 7 and 8 on the ground photograph are also evident on the aerial exposures. In band 7, the soil and vegetated areas are dark and can not be distinguished while the sandstone is light. In band 8, the sandstone and vegetation have light tones and can not be separated, while the silty surface soil is dark.

Figure 57 demonstrates where differences in items of possible interest for soils mapping are not differentiated on B&W photography and

that in order to differentiate such items, special bands in the spectrum need to be obtained. Figure 58, which contains a color ground photograph and color aerial photography of the same site as that of Figure 57 is included to demonstrate an important advantage of color over B&W. As noted in Figure 58, the three items, silty soil, sandstone exposure, and vegetated areas are easily differentiated on the color photographs (even on the smaller scale aerial photograph Figure 58b). Thus, no special filtering system is required. In addition, there would be no doubt in an interpreter's mind as to the identification of these features. From the study of the B&W alone, an interpreter would have no indication that these two areas of similar tones are actually two different features.

A nine-lens photograph of an area of sand dunes and sand and gravel terrace deposits (Site I) is shown in Figure 59. The figure is used to show the potential of multiband photography for separating coarse-textured soils (i.e., larger than the No. 200 sieve). Exposed sandy soils in the sand dunes (item 1), exposed sands and gravels (item 2), and gravel roads (item 3) (delineated in band 7) all have light tones in bands 1 through 7. In band 8 however, the exposed sands in the dunes remain light in tone while the exposed sand and gravel deposits and the gravel road have a darker tone. This tonal relationship is also evident in band 9, but to a lesser degree. These tonal relationships do not occur when these deposits are covered with vegetation of any form (item 4).

Multisensor Comparisons. Several flights were secured during the research project in which aerial photography, infrared and radar imagery were obtained during the same flight. An evaluation of the data obtained by these three sensors during the same flight generally confirms

the tonal relationships noted for the various soils and soil conditions (i.e., moisture, vegetation) in the previous section. Figure 60 includes a comparison of color photography and "artist sketches" of infrared imagery (8-14μ band) and radar imagery (K-band). Only five tones ranging from white to black are delineated in the "artist sketches"; therefore, only major trends are indicated.

The tonal relationships noted in comparing the photography with the imagery are essentially the same as noted in the previous sections. In the K-band radar imagery, unplowed bare soil areas are indicated by dark gray tones (item 1) while vegetated areas have lighter tones. Low vegetation (item 2) produces a medium tone while trees (item 3) produce very light gray tones. The sensitivity of radar to the presence of vegetation is further demonstrated by area 4 marked on the radar. At this location, the vegetation is just starting to appear; however its presence produces some scattering of the radar wave resulting in lighter gray tones than the adjacent bare soil areas. Effects of plowing (item 5) also produces a slightly lighter tone. This is probably due to the fact that the plowing action produces clods of soil which are larger in size and which form an irregular surface reflecting the energy. This causes some scatter of the radar wave to occur. The dotted lines placed in the sketch indicate that field boundaries are clearly evidenced on radar imagery. This feature is also apparent in Figure 56.

This radar sketch verifies the conclusions previously noted in comparing imagery and photography obtained at different times. There is no evidence of penetration by K-band radar and little success is achieved in differentiating various soils on this band except by correlation with

land form types. If soils information is to be interpreted from radar imagery, longer wavelengths are needed (e.g., X-band or P-band). For topographic, drainage, vegetation and land use evaluation, some useful information can be obtained from K-band radar.

The comparison of the "artist sketch" of the infrared image to the photograph similarly demonstrates that many of the conclusions on tones previously stated for infrared imagery are evident. In the bare fields in glacial tills, the lighter colored soils in the high areas are dark (item 6) while the dark colored soils in the depressions are light (item 7) (refer to infrared sketch). These tonal reversals are similar to those discussed in Figure 53 and 54. Some tonal patterns are evident however (adjacent to 8 and 9) which do not follow this tonal relationship. Area 8 represents an eroded phase of the high glacial till soil units. It is distinguished on the color photography by a moderate orange yellow color (7.5 - 10 YR 7/6). It is also distinguished on the infrared imagery because it has a light tone instead of a dark tone. This may be a result of the exposure by erosion of the darker colored and finer textured subsurface soil on the glacial till. This material has different thermal properties than the surface soil. The reverse occurs in area 9 (refer to imagery). A depressional glacial till soil which is dark on the photography is dark on the imagery instead of light as for area 7. This tonal relationship indicated that a wet condition exists in area 9.

Other features noted on the infrared imagery are the tonal patterns due to vegetation and farming practices. Areas of grass and trees (items 2 and 3) register dark gray to black on the imagery. A stubble field (item 10) registers moderately dark gray. Light tones are noted

in certain areas in pasture fields (around item 11). In comparing the areas to the photograph it is seen that these tones are present on the slopes of hills where erosion has taken place exposing the soils through the thin vegetative cover. The effect of farming practices is also demonstrated. Recently plowed soils (item 5) have a lighter tone on the imagery than the same soils which were not plowed (item 6). The difference in this case is due to the turning over and exposure of the darker colored soils during plowing. These darker colored soils absorb more heat, radiate more energy in the infrared and are correspondingly lighter.

In comparing the results obtained from the study of multisensor data obtained at two different periods of time (discussions for Figures 53, 54 and 55), to those obtained from multisensor data obtained concurrently (discussion for Figure 60), it is seen that certain basic tonal patterns for soils and soil conditions were distinctive in both. However, these patterns are not unique because at any given time, various parameters can cause these pattern relationships to change. It was shown in Figure 60 where various conditions cause different soils to have the same tone on the imagery or cause the same soil in two different locations to have different tones on the imagery. Therefore, neither infrared or radar imagery can be utilized by themselves to distinguish between different soils or soil conditions. The imagery (infrared more so than radar) however, is a very valuable supplementary source of information which can assist in the separation and interpretation of soils and soil conditions when used in conjunction with aerial photography, or as demonstrated in Chapter 4, with field measurements.

Multichannel Comparisons. The multichannel imagery covered the range from the near ultraviolet to the far infrared in numerous bands

(exact number classified). Unlike the other multisensor systems where images of different scales, resolution and format were obtained, this system provided imagery in all bands at similar scale, resolution and format. This permitted a better comparison of tonal relationships to be made between channels.

To demonstrate some of the tonal relationships obtained for various materials, the reflectance of various items were measured in each band with the reflection densitometer. The density values obtained by the densitometer were converted to reflectance by the relationship[1]

$$\text{Density} = \log_{10} \frac{1}{\text{Reflectance}} \tag{5.1}$$

or, solving for reflectance,

$$\text{Reflectance} = \frac{1}{\text{antilog}_{10}\ \text{Density}} \tag{5.2}$$

These values were then normalized for each band by determining the reflectance of the lightest object (R_L) and the darkest objects (R_D) in each band and using these as the one hundred percent and zero percent reflectance points respectively. The normalized reflectance (Rn) for each object was then determined by the following method:

$$R_n = \frac{(\text{Reflectance of Object} - R_D)}{R_L - R_D} \times 100 \text{ percent} \tag{5.3}$$

Since both reflectance and emittance are being evaluated, the values plotted will be referred to as normalized response.

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[1] The relationship normally shown is that between density and transmittance where

$$\text{Density} = \log_{10} \frac{1}{\text{Transmittance}}$$

For reflection density readings, reflectance was substituted for transmittance (29).

These normalized values were plotted in the respective region of the spectrum and the points connected to obtain a spectral response curve or signature for the various target materials of interest.

A B&W photo mosaic showing the conditions existing at the time the multichannel imagery was obtained and the location and description of the various features measured with the reflection densitometer are shown in Figure 61. Examples of the spectral response signatures obtained for the various target materials are included in Figure 62. These curves are divided into three groups. Figure 62a includes spectral response signatures for bare soils and rock units; Figure 62b includes spectral response signatures for bare soils whose tones vary from those in Figure 62a due to farming tillage practices; and Figure 62c includes spectral response signatures for various vegetation conditions present in the area. The abscissa representing spectral bands is not plotted to scale. The wavelengths shown at the bottom are only intended to indicate the regions of the spectrum included in each of the spectral bands delineated. They do not specify the bands sensed by the multichannel sensor.

In the analysis of imagery, five basic shades of gray are easily distinguished although more are evident. These are light (L), medium light (ML), medium (M), medium dark (MD), and dark (D). These are the five basic tones used in all the "artist sketches". In an attempt to facilitate comparisons between the density readings and these basic tones recognized on the imagery, the normalized response ordinate is divided into five zones corresponding to the basic tones.

The normalized response as a percent included in each zone is as follows:

dark (D)	-	0 to 25	percent
medium dark (MD)	-	26 to 45	percent
medium (M)	-	46 to 65	percent
medium light (ML)	-	66 to 85	percent
light (L)	-	86 to 100	percent

These zones were determined by qualitatively rating various target materials in various bands into these five basic tones. The normalized response values obtained for the various materials were then compared with the ratings. The zones were then selected so that the response values obtained from measurements for the various materials were included in the zones corresponding to the qualitative rating for the same material. This technique facilitates comparisons between the spectral response curves, the photographs, imagery and even artist sketches.

An analysis of the spectral response signatures for the soils and rock units (Figure 62a) confirms many of the tonal relationships previously noted in comparing various film and sensor types. Comparison of glacial till soils (curve 10, depressions and curve 11, highs) indicate that in the visible region the high soils are light and depression soils are generally medium to medium dark. In the far infrared there is a tonal reversal and the depression soils are light and high soils dark. The tonal reversals have been noted in Figures 53, 54 and 60.

Curves 1 and 9 also represent glacial till soils but note the difference in their spectral response curves. Curve 1 represents a glacial till soil with a thick (4-5 feet) cover of loess or silt. No significant difference can be noted between this soil and the glacial

till soil in high position (curve 11) until the far infrared band where the silty soil (curve 1) remains fairly light while the other glacial till soils in high position become dark (curves 9 and 11). The difference in response of glacial till soil represented by curve 9 from the others (curves 1 and 11) is due to the color of the bare surface soil. On the B&W mosaic in Figure 61, points 9 and 11 look very similar in tone but if the same area is checked on the color aerial photograph in Figure 58 it is noted that point 9 has a darker brownish color compared to point 11. This is the reason for its darker tone in the yellow-orange bands. In other regions, it is very similar in tone to that of number 11. Both soils represented by curves 1 and 9 are distinctly different than the depressional glacial till soil (curve 10) in most of the regions except for possibly the photographic infrared region.

The remaining spectral response signature curve shown in Figure 62a is for a sandstone bedrock exposure. As noted in Figure 61, the sandstone exposure is very small. It could not be directly measured on the imagery with the reflection densitometer so its value was estimated based on comparison to other areas of similar tone which could be measured. The sandstone has a high response in all bands except the photographic infrared. As far as could be determined, curve 5 is also typical for sand dunes (point 15 Figure 61). The sand dunes are also of limited exposure and are evaluated in a similar manner to that of the sandstone except that the sand dunes are not present on all bands. For the bands evaluated, the two are very similar. The similarity of tone of these two has been verified from comparisons on other photography and imagery available (refer to Figures 53 and 61 where the dunes and sandstone are both evident).

A very interesting and important fact is noted in studying Figure 62a. It is that all soils and rocks represented by these curves, have a much lower spectral response in the photographic IR band than in the other bands. This is important because it indicates that less tonal differences between soils will be evident in this band and thus, it will be harder to delineate the various soils and rock units in this region.

The effect of various farm practices on the tones obtained in the various bands is demonstrated in Figure 62b. All of these curves represent soils recently plowed. Curve 4 represents a field plowed a few days before the flight. Curves 3, and 14 represent fields plowed the morning of the flight (flight performed in the afternoon) and curves 2 and 13 represent areas being plowed during the flight or a very short time prior. Soils represented by curves 2, 3 and 4 are glacial till soils predominantly in the high topographic position and those of curves 13, 14, sandy soils of the flood plains. The density values for curve 2 were estimated in a similar manner as for the sandstone since this soil exposure was limited. The features to be noted are: (1) the response curves for soils 3 and 4 are very similar except for slight tonal reversals in the photographic IR and IR bands; (2) the curves for soils 2 and 13 are similar throughout the spectral regions studied while that for 14 is similar in all bands except the middle and far IR bands; and (3) comparing the glacial till soils of high position in Figure 62a and 62b it is noted that the spectral response for similar soils is different.

The variations in the response between, (1) the individual soils, and (2) those recently plowed and those not, are predominantly due to two tonal factors. These are moisture and intrinsic soil color. These

factors account for most of the differences noted. When a field is plowed, the lower layers of soil are usually turned over and exposed on the surface. These lower soil layers are usually darker in color and wetter than the surface soils. When the soil is first turned over the moisture effect is the controlling factor resulting in darker tones in all bands regardless of texture (e.g., curves 2 and 13). As these soils dry out, the effect of moisture is decreased and that of soil color becomes prominent (e.g., curves 3 and 14). The sandy soil (curve 13), whose surface had dried out a little before the flight, still had dark tones in the bands from the UV through the photographic IR because of its dark brown soil color. However this dark brown color resulted in a tonal reversal in the infrared region producing a light tone. The till soil (curve 3) is a little more difficult to explain. On drying, the intrinsic soil color was lighter than that of the plowed sands, but still darker than the soils not plowed recently. These tonal relationships are evident on the B&W mosaic in Figure 61. The darker intrinsic color of these till soils also resulted in light tones in the infrared regions. The effect of its darker color was less prevalent in the visible region except in the violet and yellow-orange bands. This is similar to the effect noted for the darker brown till soils, Curve 9. These examples demonstrate that in the matter of only a few hours, drying of soils can vastly change tonal patterns.

Curve 4 is included to demonstrate the effect of drying on the tonal pattern (soil plowed a few days before). It is observed that this soil response appears a little lighter in the visible region and correspondingly a little darker in the far infrared region. With further drying,

of the soil, the response would probably be similar to conditions represented by curve 9 (Figure 62a).

An example of the tonal relationships between plowed and unplowed fields of glacial till in the visible and the far infrared region can be seen by comparing Figure 61 (field including points 2 and 3 and field immediately to east) with an artist sketch of this area shown in Figure 50, (page 228).

The last group of curves in Figure 62c shows the differences in spectral response signatures obtained due to various vegetation conditions. Curves 6 and 12 represent fields of winter wheat while curves 7 and 8 represent pasture fields. It is interesting to note the general resemblance of the form of the curves to typical spectral reflectance curves obtained for vegetation (refer to Figure 13, page 70). All the curves in this figure indicate that the presence of vegetation results in dark or medium dark tones in all bands but the photographic IR. Previous discussion indicated that soils have a low response in the photographic IR. Therefore, the photographic IR is an excellent band for delineating tonal effects due to vegetation.

The difference in response between the pasture fields (curves 7 and 8), is that the field containing point 7 has bedrock close to the surface and its influence is indicated by the light streaks in the field (see Figure 61). This affects the overall tonal response resulting in slightly lighter tones. Pasture fields can generally be distinguished from winter wheat by lower reflectance in the photographic IR range of the spectrum.

An interesting phenomenon is noted in the field represented by

curve 6 (winter wheat). This curve resembles curve 12 in all bands but the photographic IR. In that band it is not as light. In fact, in the photographic IR, it is hard to tell the difference between this field and the adjacent one which was recently plowed and has no vegetation (represented by curve 4). This feature can be seen on the aerial multiband photography (band 8 in Figure 55). From investigation of this phenomena in the field, it was determined that field 6 was planted two weeks earlier than field 12. In addition it was discovered that this field had been planted in corn the year before while field 12 had been planted with a low cover crop. It has been suggested by a botanist that the tonal patterns may be reflecting differences due to nitrogen levels in the fields. This can not be verified, but similar effects of previous planting history on variations in tonal patterns obtained for similar crops has been reported by C. E. Olson (135). This example demonstrates the possible variety of parameters that can cause tonal variations.

One final feature can be noted in reviewing the spectral response curves in Figure 62. Many of the curves for soils (but not all) show a dip in the yellow-orange bands. Thus tonal differences between some soils are increased in this band. This may explain why it is easier to delineate some soil boundaries on color photography using a red filter (Wratten 25). This filter limits the range to approximately 0.60 to 0.70 microns (41a) which covers this region.

It is evident from the discussion that the use of simultaneous multichannel imagery offers a great potential for identification of various soils and for identifying various soil conditions which affect the tonal patterns of the imagery (e.g., effects of moisture, vegetation,

farming practices). The spectral response signatures obtained by density measurements combined with normalizing procedures demonstrate a valuable method for evaluating the response of various target materials in different regions of the spectrum from an airborne platform. This should prove to be an excellent method for determining spectral bands of maximum contrast for the separation of soils of interest. It should prove to be much better than the method of using laboratory or field spectral reflectance curves to determine this factor. The main drawback to this system is that the amount of imagery obtained for analysis by normal interpretative methods becomes voluminous. This requires the development of automatic interpretation systems. Multichannel systems are ideal for this approach since scale, and format are identical on all channels. Using normalizing procedures and just five basic tones; with ten channels there would be 5^{10} possible tonal combinations, with twenty channels, 5^{20} possible combinations, etc.... This approach is being investigated for computer evaluation by several investigators [Hoffer and Miller (64) Lowe, et al., (95)].

<u>Analysis of Various Film and Imagery Data - Elements of Form</u>

The elements of form are as important in the interpretation of soils and soil conditions as those due to tone and texture, and sometimes more important. To properly evaluate the elements of form, stereoscopic capabilities are generally necessary. This feature limits the use of imagery for interpreting elements of form. However, it does not eliminate these types as general information on topography, drainage and erosion are often evident on the imagery, either directly or indirectly.

The main comparisons discussed are those for the delineation of

drainage patterns and the effect of scale of photography on interpretation of soils. This latter item affects the ability to distinguish features of topography and erosion.

Delineation of Drainage Systems

Drainage conditions were evaluated on the various film and imagery types obtained on the project. For the actual drawing of the detailed drainage system, (with proper position and orientation) stereoscopic study was required. This eliminated the imagery as far as preparing the drainage maps, but not with respect to location of drainage ways or drainage patterns. Figure 63 shows a comparison of drainage evident on B-I and B&W photography and daytime and nighttime infrared imagery. It is evident from this figure that the creek (Little Pine Creek, Site III) is most easily distinguished on the nighttime infrared imagery than on any of the other types. All the intricate bends of the creek are clearly indicated. The details of the creek are least evident on the B&W photograph. Intermediate between these extremes and about equally distinct is the evidence of the creek on the daytime infrared and B-I photograph. Thus one may conclude from this, that the best type for drainage delineation is nighttime imagery. Actually, the reverse is true, because of distortions in the imagery introduced by the scanning systems and the lack of stereoscopic coverage, the infrared systems are the least desirable for preparing detailed drainage maps. They are of value as supplementary information in that they clearly indicate the channels where water is flowing. Nighttime imagery can also indicate which channels are intermittent at the time the imagery was obtained (see discussion for Figure 54).

To evaluate the various film types for the purpose of drainage delineation, separate drainage maps were prepared from B&W, C-P and C-I film types for a portion of Site III. B-I was not analyzed as it was considered comparable to C-I for drainage delineation. The conclusions reached, based on a comparison of the drainage maps produced from these three film types are as follows:

1. The most drainage detail obtained and the most confidence in separating streams into perennial and intermittent were obtained with the C-P and C-I film types individually. The detail mapped on the B&W was almost equivalent to that obtained on the other two types (about 90 per cent of the detail). The main difference however between the B&W and the others, was the confidence in choice of channel flow (i.e., perennial or intermittent). In addition, the accuracy of the location of the channels was lower on the B&W.

2. The date of the photography was more critical than the type of photography used. For all practical purposes, B&W is satisfactory for preparing the drainage map during the period of the year (May in this case), when the leaves are not on the trees. At other times of the year, when the leaves are out, the advantage swings to B-I or C-I because the black tones produced by water are more easily distinguished through the tree foliage.

Effects of Scale

The influence of scale of photography on the interpretation of soils is a tenuous item. Since soils are not features that can be directly seen and interpreted on photography, the use of a larger scale does not necessarily insure an increase in soils information interpreted. It is

true that at a larger scale, more microfeatures and details can be identified and analyzed, but opposing this, a smaller field of view is obtained and more data has to be analyzed for the same area. Several different scales have been reported in the literature for soils mapping ranging from 1:50,000 down to 1:5,000; however, no optimum scale has been reported.

To investigate the effect of scale on soils mapping, two scales of photography were obtained in all the 1965 flights. These were 1:10,000 and 1:4,000. In the final photographic flight in May, photography at a scale of 1:24,000 was obtained in addition to the other two. The photography was all obtained with a Wild RC-8 camera with a six-inch distortion free lens.

The evaluation of the various types of films at these different scales with respect to soils mapping led to some very enlightening results. It was determined that the optimum scale for performing detailed soils mapping was not just a function of the scale of the photography, but was also a function of the type of film used, and the magnification capabilities of the viewing system. Other pertinent items include the camera characteristics, the exposure and processing of the film, but these features were considered fixed for this comparison. The same camera was used for all the film types and visual inspection indicated that the exposure and processing was satisfactory. The combination of scale, film type and magnification capabilities of the viewing system determines the resolution[2] of the final data available for analysis. For this project the viewing system utilized (zoom stereoscope with range of magnification from 2.5X to 20X) was not a limiting

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2 Resolution is defined as "...The minimum distance between two adjacent features, or the minimum size of a feature which can be detected by a photographic system or radar system." (173).

factor as all the film types investigated degraded or became uninterpretable before the maximum magnification potential of the viewer was reached. Thus, in final analysis the main feature other than scale was film type.

For a given scale, differences were noted between the various film types as to the amount of detail that could be obtained. In comparing positive film types at the same scale, it was observed that the greatest magnification possible, before the image degraded, was obtained in viewing the C-P and C-I transparencies. In addition, the various color tones on these types increased the contrast between various objects and their background (e.g., delineate boulders in a pasture field) making it easier to delineate smaller objects. These characteristics enabled more details to be identified from these types than from the other film types studied. In fact, it was noted that approximately equivalent details could be interpreted from small scale color photography (1:24,000) as from medium scale black-and-white photography (1:10,000). This factor was substantiated by performing detailed mapping of Site II utilizing different film types. These maps are included in a subsequent portion of this chapter and indicate the important factors for determining an optimum mapping scale. That is, for similar detail of mapping, smaller scale color photography can be used to give comparable data to larger scale black-and-white photography; therefore, compensating for the difference in cost between these types.

A qualitative rating of the various film types, based on the amount of detail evaluated (function of magnification and contrast) is shown in Table 9. The ratings shown were based on comparisons of the various

types to black-and-white photography used as the average. All films compared were approximately the same scale (1:10,000). Only positive films were considered in the first rating. The second rating shown in this table indicates the relative suitability for image magnification of the various film positives and negatives compared to black-and-white photography (positive print).

Table 9. Qualitative Ratings of Various Film Types.

Rating	Interpretation of Details[a]	Magnification[b]
Excellent	C-P, C-I	C-P, C-I, B&W (n)
Good	C-P/C-N	C-N, B-I (n)
Average	B&W, B-I	B&W, B-I
Poor	B&W/C-N	B&W/C-N, C-P/C-N

a - positive prints considered only
b - includes positives and negatives (n)

In the evaluation of the film types it was observed that: (1) greater magnification (good to excellent) was obtained on the negatives than on prints from them; (2) both B&W and C-P prints made from the color negatives (C-N) could not be magnified as much as the other types; and (3) the least detail was obtained from the B&W print from the color negative while good detail was obtained from the color print from the color negative because of the increased contrast the colors provided.

The evaluation of the large scale photography (1:4,000) for soils mapping did not add much additional information to that already obtained from the analysis of medium scale photography. The only advantages obtained in utilizing the larger scale photography was that an increased

accuracy was obtained in drawing boundaries between various soils and finer details could be evaluated. This was of value in certain cases in separating soils (e.g., differences in crop heights related to differences in moisture regions or soil differences). These differences were generally finer than needed for detailed soils mapping. A major disadvantage of this low scale was the large increase in the number of photographs to analyze and the limited area coverage per photograph.

Based on the analysis of the various film types and scales it is concluded that an optimum scale for detailed engineering soils mapping is a medium scale, (i.e., between 1:8,000 to 1:15,000) but the scale depends on the type of film used and the viewing system available. In the evaluation of imagery, the only consideration of scale which is important for soils analysis is to obtain the largest scale available for the sensor system used. Scales of imagery are much smaller than those obtainable for aerial photographic systems, the resolution poorer and no stereoscopic coverage is normally available. Therefore, for detailed soils mapping, the imagery is just a supplementary source of information for identifying and delineating various soils. The mapping of soils and delineation of boundaries will still have to be accomplished on photography.

Effects of Parameters on Interpretability of Photography and Imagery

The various parameters influencing each sensor have been discussed in detail in Chapter 3. These discussions indicated that the various parameters influence the results obtained under given circumstances. The influence of many of these parameters on the pattern elements used in interpretation have been noted in the analysis of the photography and

imagery obtained. For qualitative analysis however, many of these are not significant as the interpreter adjusts for the variations due to the parameters during the analysis. The parameters discussed here are those which have a significant influence on the identification and mapping of soils.

The effects of some significant parameters have already been demonstrated in the discussion comparing the various types of film and imagery. These include: (1) the effect of contrast of target material with surroundings (illustrated in Figures 52, 57 and 58); (2) reflectance properties of soils (illustrated in Figure 62); and (3) instrument settings (illustrated in Figure 55). Additional parameters of significance for qualitative soils analysis include seasonal effects and time factors for aerial coverage.

Seasonal Effects

The influence of the season of the year on evaluation of soils and soil conditions is demonstrated in Figure 64. This figure includes C-P coverage obtained on July 26, 1965 and C-P/C-N coverage for October 25-26, 1965. For the complete study of seasonal effects, however, reference should also be made to Figure 60 showing C-P photography obtained on May 13, 1965 and Figure 52 showing C-P photography obtained on May 4, 1966 for the same site. The comparison of these figures illustrates some of the variations occurring during one year of flights.

A comparison of the color photographs for the different times of year indicates that October is the least desirable time (most of area still covered with vegetation) while May is the best time (the plowed

fields expose the various soils). This example verifies a conclusion stated by many other investigators. An item to note in comparing these four photographs is that if soil boundaries are drawn based on tonal patterns alone, four different soils maps would be produced depending on the date of photography. In actual practice, tone is just one of the elements evaluated.

In comparing the tonal patterns present on the four photographs several pertinent features are noted. Comparing the May 13, 1965 (Figure 60) and the May 4, 1966 (Figure 52) photography, it is observed that where the same fields are plowed on both dates similar tones are obtained (e.g., point 8, 5/13, point 4, 5/4). However, where different farming practices are evident, different tones are obtained (e.g., points 2, 5 and 6, 5/13 and points 3 and 5,-5/4).

Also of importance in delineating soils are the moisture conditions existing at the time of photography. In the May flights, the moisture contents are higher and tonal boundaries between high and low areas are quite distinct. The moisture effect is also evident in the July photography although not directly. The thicker growth of vegetation in the depressions outline these areas (point 2, Figure 64). This growth difference between the high and lows is due to difference of moisture available to the plants. It is interesting to note, that because of this vegetative effect, it is easier to separate the depressional areas and high areas on this date photography than on the other type. This is an exception to the statement previously made on the necessity of having exposed soils in order to map them. The least contrast in soils is evident in the October coverage which is a drier time of year. Even in

the plowed fields it is more difficult to differentiate the soils based on tonal differences.

Time Factors for Aerial Coverage

Variations in interpretability due to the time the aerial coverage is obtained within a given season or within a given day is considered under this item. Figure 65 demonstrates the differences in information and soils boundaries that can be obtained with only one days difference in flight. The May 2, 1966 photography was obtained the day after a two day period of rain. The presence of high moisture conditions at this time obliterated much of the differences between soils (fields 1 and 2). On the B&W photograph made from the color negative obtained a day later (May 3) a greater variety of tonal differences related to soils are noted on the photograph (field 2). Apparently, more soil boundaries based on tonal differences can be differentiated on this photography than on the previous one. In field 1, subsurface drainage tiles are more apparent on the May 3 photography (diagonal lines crossing the field) which were not as distinct the day before. In fact, this was the first time these drainage tiles were clearly evident in the photography obtained. The selection of a date for a flight within a particular season can be an important factor in obtaining information on soils and soil conditions for detailed mapping projects. A period in the spring season, a few days after a rain would be ideal. This is difficult to plan for as there are few enough suitable flying days available.

The effect of time of day for obtaining soils information from infrared imagery has been discussed previously (chapter 5, pp. 249-250 and chapter 4, pp. 230-233). With respect to film types, the time of day is

most critical for aerial color photography. Haze effects and exposure latitude have a limiting influence on time of day for obtaining photography. For interpretation of soils, color photographs taken at about noon time at low altitudes (5,000 feet or less) give the best results.

Examples of Detailed Engineering Soils Mapping

Detailed maps were prepared for Sites II and a portion of Site III, to assist in determining the optimum system for performing detailed engineering soils maps. Different approaches were utilized in mapping each site to determine the effect of different items such as scale and film type on preparing detailed soils maps. In addition to evaluating what combination would be optimum for soils mapping, these maps demonstrate the degree of detail that can be obtained from an interpretation approach utilizing various film and imagery types in conjunction with limited field investigations. Further statistical sampling and testing of the various map units delineated is necessary to define soil parameters. In addition, accurate location of soil boundaries by projections to a base map or by rectifications of the photographs is required.

Comparison of Various Maps Prepared for Site II

A series of four different maps prepared for Site II show the difference in detail obtained based on variations in film type, scale and source of information. The maps for Site II were prepared from the following sources:

1. Black-and-white photography - 1:10,000 scale;
2. Color photography (transparencies) - 1:10,000 scale;
3. Color photography (transparencies and color prints from color negatives) - 1:24,000 scale; and

4. Agricultural Soil Survey Map for Tippecanoe County - 1:31,680 scale.

The photography obtained May 2-6, 1966 was used for the preparation of the maps by aerial photographic interpretation procedures. In the interpretation of the photography, the boundaries were drawn on acetate overlays. The map produced at the photo scale was then reduced to the 1:24,000 scale (where necessary) by projection methods. An engineering soils map was prepared from the Agricultural soil map by grouping various agricultural soil units which are similar for engineering purposes. This map was enlarged to the 1:24,000 scale for comparison with the other maps.

The legend for the maps illustrated is shown in Figure 66. The comparisons shown are between the maps prepared from color and black-and-white photography at medium scale (Figure 67); between color photography at the two different scales (Figure 68), and between the medium scale color photography and the map prepared from the agricultural soil survey map (Figure 69). The overlays included with Figures 67, 68 and 69 indicate the basic land forms interpreted from the aerial photographs and the agricultural report. As noted, the land forms interpreted from the aerial photographs (different types and different scales) are basically the same. The land forms determined from the agricultural report are comparable except no distinction could be made between ground moraine and ridge moraine in this area from the agricultural soil units or from the soil survey report (176). This type of land form mapping annotated with soil textures is the same as normally developed for small scale engineering soil mapping in Indiana (refer to Figure 34). Thus, as

illustrated by the various maps, small scale stereoscopic photography would be suitable for development of county maps. The maps shown beneath the overlay indicate the detail differentiated for a detailed engineering soil map.

A comparison of the detail that was obtained from B&W photography at medium scale to that obtained from C-P photography at medium scale is shown in Figure 67. The B&W was taken as the standard type in this comparison and was interpreted first. Great difficulty was encountered in delineating boundaries initially in the northern part of the site. Tonal differences were noted and related to topography but it was difficult to determine which tonal differences represented soil differences as opposed to differences due to vegetation, moisture or intrinsic soil color. After the map was produced from the color photography, the B&W photography was again interpreted. Based on the tonal relationships determined from the color, it was then possible to further separate some of the tonal patterns on the B&W photography. This second stage of mapping of the B&W is shown in Figure 67. Except for these features, the maps shown in Figure 67 were developed independently of each other.

Comparisons of the two maps demonstrate the following items:

1. On the C-P photography, differences between the glacial till prairie and glacial till forest soils was readily differentiated. This differentiation was more difficult on the B&W photography. This feature was also discussed in relation to the photographs shown in Figure 52.

2. The completeness of mapping of the soil boundaries interpreted directly on the C-P photography (May) without assistance from other types of photography or dates of photography was much greater than

on the B&W photography. This is shown by the relative amount of the boundaries that are dotted on the maps (dotted lines indicate information added from additional photography). This indicates that having only one type or season photography available (the normal case), more information can be directly interpreted from C-P than the B&W photography.

3. The main differences between the maps are in the northern third, and in most cases, indicate the extent of the depressions mapped in the glacial tills. Larger areas of depressional soils were delineated on the B&W because it was difficult to distinguish between tonal differences due to soils, and those due to other factors. In this case, intrinsic soil color was the major confusing factor. These ground moraine soils were predominantly developed under prairie conditions and thus even the high soil areas have more organic matter on the surface producing a darker tone. Another significant difference occurred in the right central portion of the maps relative to the extent of bedrock exposed at the surface. Overall, the more accurate boundaries were obtained from the analysis of C-P photography.

4. The dotted boundaries shown on the C-P map were determined from the May 13, 1965 C-P photography. The dotted boundaries on the B&W map were determined from the May 6, 1966 B-I photography and the October 25-26, 1965 B&W photography. Details of borders vary from zone to zone. Complete detailed mapping is not always possible from photography of a single date. The main reason for this is the presence of vegetation cover which limits the ability to distinguish and map specific soil boundaries. However, at different seasons, land use practices can change these conditions at any given point making it possible to delineate some

boundaries which could not be delineated previously. Compare the C-P photography of Site II shown in Figures 52 and 60. These photographs were taken about one year apart.

Based on the analysis of these two types, color photography was chosen as the basic type for making further comparisons.

Figure 68 shows a comparison of maps prepared from color photography obtained at two different scales. It is observed that differences between prairie and forest glacial till soils can also be distinguished on the small scale color photography. The main difference between the two maps is the amount of detail delineated and the accuracy of some of the boundaries. The difference in detail is largely in the differentiation of the small depressions in the glacial till. These small depressions are beyond the resolution capabilities of the film-viewing system utilized. The major point of concern, however, is the inaccuracy in boundaries. Major differences are noted in the left upper third of the maps, in the basin deposit areas in the right central third of the maps, and in the extent of terrace deposits mapped as shown in the left bottom third of the maps. These differences are also due to the inability to distinguish slight topographic breaks which help differentiate between different soils.

Comparing the map prepared from small scale C-P to the one prepared from medium scale B&W in Figure 67, it is seen that although not as much detail is mapped, more of the soil boundaries are more positively identified on the small scale C-P than on the larger scale B&W.

The final comparison is between the map produced from the medium scale C-P and that produced from the Tippecanoe County Agricultural Soil

Survey Maps as shown in Figure 69. The original agricultural soil survey map was prepared by field exploration and mapping techniques using enlarged aerial photographs (B&W) as a base map in the field. The original soil map is published in much more detail than the one shown here (refer to Figure 35). The field investigations are generally limited to the upper three to six feet. Thus some soil profile differences which are significant in engineering mapping are not indicated on the agricultural soil map. Comparisons of these two maps indicate the following:

1. On the agricultural soil map, differentiation can also be made between the soils intergrading between forest and prairie soils. In addition differences are noted between the depressions formed under grass cover and those under tree cover. These two distinctions can not be made on the C-P photography.

2. Except for the above feature, the final detail mapped from medium scale C-P photography is greater than that produced from the agricultural map. For example more bedrock is mapped from C-P photography than is shown on the agricultural map.

3. Except for some slight boundary differences, and the amount of detail shown the two maps are fairly similar in the soil units differentiated. This would indicate, that where recent agricultural soil survey reports are available, a fairly detailed engineering soil map can be prepared rapidly from the survey report. Only limited additional investigations or analysis would be required to bring it up to the desired detail and accuracy.

The previous maps were prepared to demonstrate the differences in detail obtained between maps prepared from different sources and at

different scales. An attempt was made to prepare these independent of each other which was not always possible. For actual detailed engineering soils mapping, all the information would be used to develop the map. This is the approach demonstrated for the preparation of the detailed engineering soils map for a portion of Site III.

Detailed Engineering Soil Map of a Portion of Site III

The detailed engineering soils map prepared for a portion of Site III is shown in Figure 70. This area was chosen as there was very little background information available for the area. The map was prepared utilizing all the remote sensor information developed for this site including the field exploration data. This map furnished the opportunity to determine which sensor data is of maximum use and the field investigations required both in developing information on soils and geology and in obtaining ground truth during the flight.

Color photography at the scale of 1:10,000 was used as a base map for preparation of the map. Boundaries were drawn on acetate overlays on the photography and the final map was reduced to a 1:20,000 scale. In delineating the soil boundaries on the C-P and C-I film types studied, the use of a single colored filter in the eyeguard of the zoom stereoscope was found to be very helpful. The use of the red filter (Wratten 25) with the C-P film and the green filter (Wratten 58) with the C-I film was the most successful in differentiating between different soils. In the spectral regions transmitted by this filter (approximately 0.60-0.70μ) an increase in contrast between various soil types is indicated on the spectral response curves (see Figure 60); therefore, making it easier to distinguish between them. This same feature explains the

increase in contrast using the green filter with C-I film. On C-I film, the red colors are recorded on the green layer of the film; therefore, the maximum contrast previously seen in the red region on C-P is now present in the green region on C-I. The map (Figure 70) encompasses an area approximately 3-1/2 miles by 1-1/8 miles and contains twenty-five different map units. The major land forms are indicated by a letter symbol, while the minor subdivisions within the major units are indicated by hatchure lines. In the final map, no attempt was made to differentiate between the boundaries delineated on the C-P photography or that furnished by other types of photography and imagery although this distinction was made on the work sheets in the preparation of the map. An estimate indicates the following per cent of the boundaries delineated from the various types.

C-P May 1966 - 65 percent

C-I May 1966 - 20 percent (mostly depression areas)

Color films from other dates - 10 percent

Infrared imagery - 5 percent

The C-P photography obtained in May was best for delineating soils related to the pattern elements and medium scale was the optimum scale to use. C-I photography assisted in outlining the wet depressional areas and was best for delineating drainage conditions. The value of the imagery for delineating boundaries between soils is generally poor because of its smaller scale and poorer resolution. The main value of the infrared imagery is in furnishing supplementary as well as converging evidence to increase the accuracy of interpretation of soils and soil conditions.

Field Measurements In Qualitative Analysis

An evaluation of the value of ground data in interpreting and delineating various soils and soil conditions for detailed soils mapping indicates that the type of data needed falls into two main categories. These are: (1) collection of ground truth data obtained during the aerial flight which are used to evaluate the effects of various parameters on the photography and imagery; and (2) supplementary field data obtained to indicate the type of soils and rock units present in the area and their engineering properties. The first type is collected during or as close to the time of the aerial flight as possible, while the latter is obtained after the first phase of interpretation. The main purpose of an aerial photographic interpretation approach is to keep the latter type of field data collection to a minimum.

Ground truth data collected during the flights which were of assistance in interpreting and delineating soils and soil conditions on this project include: (1) radiometer readings; (2) ground color photographs indicating soil color conditions; (3) inventory of land use practices and vegetation; (4) collection of meteorological data. All of these items are of some assistance in determining the reasons for the tonal patterns present on the imagery and photography and assisted in explaining anomalies. The main limitation encountered with the data collected is that some data obtained on the ground did not represent areas large enough to be distinguished on the imagery or photography. For this reason, trends noted on the ground are not always seen on the imagery or photography. Examples of the application and limitations of some of the data collected in the field are discussed in Chapter 4.

Ground radiometer readings are helpful in planning aerial flights for infrared sensor systems and for obtaining ground truth data during flights to assist in evaluating the imagery. Field measurements prior to flights can be used to determine the time of maximum contrast between the soils of interest. They can also be used to determine what apparent temperature range would be best to scan with to obtain maximum contrast between the soils of interest. For control and comparison purposes, it has been found useful to record the apparent temperature of a body of moving water. This remains fairly constant during the day (refer to Table 6) and thus can be used as a reference tone on the imagery.

The collection of meteorological data prior to and during the flight is of assistance in explaining anomalies which can not be related to the soil, moisture and vegetation. The value of this data to a flight depends on the proximity of the data collection station to the test area. Long term precipitation and evaporation data was found of value to explain differences in tonal patterns noted between various flights and to explain ground moisture conditions existing at the time of the flight.

Ground photographs (preferably color) taken from a high vantage point as well as close ups taken at the time of aerial flights are valuable indicators of existing conditions during the flight.

Rapid inventories at the time of flights of typical land use, vegetative cover and farming practices and annotation of these items on aerial photographs is of great assistance in correlating existing conditions present at time of flight.

Settings of the imagery scanners should be obtained so that the apparent temperature range exposed on the imagery is known.

Summary

The applications, advantages and limitations of the various film and imagery types for detailed engineering soils mapping are summarized. Recommendations on optimum mapping systems are presented. In addition, some brief comments are made, where applicable, with respect to such features as exposure latitude, color fidelity, storage, use in the field, etc..., which may limit the application of a particular type irrespective of its value for soils mapping.

Evaluation of Photography and Imagery for Engineering Soils Mapping

Based on the information and data collected, the following evaluations of the film and imagery types are indicated.

Black-and-White Panchromatic Photography. The application of B&W photography to detailed engineering soil mapping is limited by the following factors. It is difficult in many cases to determine which of the tonal factors are causing the gray tones present on the photography and different soil colors appear as the same shade of gray. These two factors result in similar tonal appearances of distinctly different soils on the photography. Considerably more field checking is required when using B&W photography for detailed soils mapping. The maximum information on soils and soil conditions is obtained from B&W photography taken in the spring.

Black-and-White Infrared Photography. Two types of B-I photography were evaluated. The normal B-I, obtained with the nine-lens camera, includes only that portion of the visible spectrum above approximately 700 millimicrons (red and infrared). "Modified" infrared

photography, taken with an aerial camera using a Wratten No. 12 filter, allows blue-green light in addition to red and infrared radiation to reach the film. The latter type was more suitable for interpretation of soils than the former because the tonal range of exposed soils was greater.

The disadvantages or limitations for soils interpretation indicated for B&W generally apply to B-I film types. It is also difficult to determine the significance of the tonal factors on the photography. The B-I has the advantage that high reflectance of vegetation enables this tonal factor to be evaluated in most cases.

The sensitivity of B-I films to moisture conditions makes this type valuable for delineating drainage patterns and for distinguishing slight differences in moisture conditions at low moisture levels.

The combination of B&W and B-I enable the differentiation to be made between tones due to vegetation and moisture. This thus increases the amount of information on soils that can be evaluated from the photography.

The exposure of B-I film can be a problem with some aerial cameras which do not have a setting for infrared film.

Color Photography. This includes color transparencies (C-P), color negatives (C-N) and color prints made from color negatives (C-P/C-N). For evaluating engineering soils, C-P photography is the most useful single film type available.

The advantage of the natural color appearance of the soils and soil conditions make it possible to determine whether the tones are due to intrinsic soil color, moisture, vegetation or cultural features. Thus

the last tonal factor, soil composition is more readily evaluated. Although the color photography has a natural color appearance, it can not be directly related to field soil colors since no color film made today can truly reproduce the variety of colors present (75)(81). This factor is demonstrated in Figure 71. A comparison is shown between Munsell color chips, and a kodacolor photograph and B&W photograph taken of the chips. The Munsell chips shown include the ten major hues (spectral colors)and three ranges of value (brightness) and chroma (saturation or purity of color) from high brightness and saturation to low brightness and saturation. Comparison of the kodacolor print to the original chips demonstrate that the film does not reproduce the true colors in the full spectrum shown. Still, it is evident that distinction can be made between most of the chips on the photograph except for a few in the low value range. The B&W photograph confirms the conclusion previously stated that distinctly different colors appear as the same shade of gray on B&W. Therefore, the ability to distinguish many more color tones (than on B&W photography) makes the color photography more valuable for soils mapping.

Other advantages of color photography are that it can be magnified more than most other film types enabling smaller features to be identified at a given scale. Also various filters can be used while interpreting the photography to limit the region of the spectrum analyzed to maximize contrast between soils.

The advantages listed for C-P film also apply to C-P/C-N except for the degree of magnification possible.

C-N film can also be used for interpretation purposes as contrasts

in soils are indicated by differences in colors. The disadvantage of using this type directly for interpretation is that the colors are not natural and can not easily be related to the effects of the various tonal factors. The advantage of the C-N type is its versatility. Color prints, B&W prints and diapositive plates can be made from the color negative. These types are satisfactory for interpretation purposes but are not quite as good as the original types (i.e., C-P, B&W). They have the further advantage that prints can be made for field use. The originals do not have to be used in the field.

The exposure and developing of all types of color film can be a significant factor. Poor results can negate any advantage furnished by the film type. Experience on this project has shown that with proper care and possibly some experimentation prior to a flight, suitable photography can be exposed and developed without having previous experience with the film types.

Color Infrared Photography. The features noted for B-I photography also apply for C-I photography except for the larger number of distinguishable tones evident on the C-I. The high reflectance of vegetation in the infrared region is indicated by red tones on the infrared sensitive red layer of the C-I film. The yellow-orange, browns, whites and blacks normally indicative of soils are recorded as blues and blue-greens on C-I. This sharp contrast of reds for vegetation and blues for soils present a distinct advantage of this film type for readily distinguishing these two tonal factors. The red tone of the vegetation facilitates the delineation of vegetation; however, the presence of soils in the blue region of the spectrum presents very little contrast between various soils.

C-I film types are not as suitable for engineering soils mapping as C-P film types. This is due to the low contrast between soils on C-I film, coupled with the factor of unnatural soil color tones and the fact that the human eye is less sensitive in this region of the spectrum than in the yellow-orange region [Evans and Hanson, figure 1.1 page 4 (45)].

Some advantages of C-I film are that it is best for delineating drainage conditions, it can be magnified more than most other film types allowing smaller features to be identified at a given scale, and special filters can be used in analyzing the film to increase contrast between certain materials.

Infrared Imagery. Because of smaller scale, poor resolution and lack of stereoscopic viewing capabilities, infrared imagery can not be used as a primary source for engineering soils mapping. Its primary value is that it provides supplementary information not obtainable by any other means which aids in the interpretation of soils and soil conditions. For example, differences between various soil and rock units can be differentiated due to the difference in thermal properties of these materials. Infrared imagery also provides converging evidence which increases the accuracy of the analysis.

It was found that the 8-14μ band was of greatest value for obtaining information on soil conditions. The 4.5-5.5μ band was suitable, but tonal differences were not as distinct. It was noted that tonal patterns in the region from 1.5 to 4.0μ on daytime imagery was similar to those of visible photography since solar reflectance was the major contributing source of energy in this band. Comparisons of daytime and nighttime imagery indicated the possibility of further differentiating between

soils and soil conditions because of the occurrence of tonal reversals.

To obtain the maximum information from infrared imagery, supplementary information such as field radiometer measurements or concurrently flown aerial photography is needed.

Radar Imagery. K-band frequency radar was of little value for interpreting soils. Tonal patterns for exposed soil areas were dark for all soil types at this frequency except for the special case when the radar signal was normal to the surface of the soils. Radar was of some value for evaluating soil conditions (e.g., vegetation, land use) although small scale and poor resolution limited the value of this feature also. The all weather capability of obtaining radar (except under conditions of heavy rain or snow) is an advantage of this type over other types analyzed.

Combination Systems. For the various combination systems analyzed, the maximum information on soils and soil conditions is obtained from the multichannel system. The development of normalized response curves from multichannel data is a powerful tool for evaluating the various tonal factors and determining which bands demonstrate the maximum contrast between soils of interest. This is the only system evaluated that has the potential for automatic differentiation of soils and soil conditions. The main disadvantage of multichannel imagery is the large amount of data that has to be handled.

Multisensor systems which obtain data concurrently or at different periods of time also enable the evaluation of the tonal factors and soils and soil conditions. Normalized spectral response curves can not be determined from these types; only relative tonal comparisons are

possible. More field work is required for these systems than for multichannel systems. Information on soils can be interpreted from data collected at different periods of times as long as sufficient field control is available to explain the changes that had occurred during these periods.

Optimum System for Engineering Soils Mapping

It has been demonstrated in chapter 3 in the discussion of "Multisensor Approaches" (page 164), that eight factors have to be considered in planning a multisensor approach. These factors include: (1) purpose; (2) economics; (3) time; (4) personnel; (5) equipment availability; (6) techniques of handling and interpretation; (7) security; and (8) area accessibility. These same factors affect the decision as to the optimum system that can be used for engineering soils mapping.

Optimum System (no limiting factors). The optimum system for performing detailed engineering soils mapping considering presently available equipment is one which simultaneously obtains multichannel imagery and aerial color photography (C-P). The multichannel imagery should provide data on various bands in the ultraviolet, visible, photographic infrared, middle infrared and far infrared regions of the spectrum available for sensing. The exact number of bands obtained would depend on the equipment available for the project. The minimum number of channels suggested is seven. This should include a band in the ultraviolet, violet-blue, green, yellow-orange, photographic infrared, middle infrared and 8-14μ in the far infrared. This would provide information on the basic trends of the spectral response curves which can be developed from the data. The use of equipment with more channels

would increase the accuracy of the spectral response curves obtained and the amount of possible data extracted, but it would also increase the amount of data to be handled and analyzed and the cost of obtaining the data.

The procurement of aerial photography to photogrammetric mapping standards is essential. The scale, resolution and mapping accuracies obtainable form multichannel imagery is not satisfactory for preparing the final map. The acquisition of color photography obtained simultaneously with the multichannel imagery provides photography from which maximum information on soils and soil conditions can be interpreted; maximum details can be seen at the given scale - magnification conditions; special filters can be utilized to increase contrast during interpretation; and suitable detailed maps can be prepared. This combination of systems should provide the maximum information with the least amount of field checking and sampling. This makes it the most desirable for inaccessible areas.

The use of a system of this type requires security clearance, access to equipment with limited availability and is very expensive. Costs in the region of one thousand dollars per hour of flying time would not be uncommon.

Alternate Systems (factors limiting selection). Several factors limit the ability of an organization to obtain the optimum suggested system. The following discussion suggests minimum systems which would obtain the maximum soils information under the specified limitation.

(a) Lack of availability of specialized equipment such as the multichannel sensor, necessitates the use of alternate systems. The

first alternate to the optimum system is the simultaneous procurement of C-P and C-I photography and IR imagery (8-14μ). Normalized spectral response curves can not be developed because the scale, resolution and format of the films and imagery types are different. However, between the three types, the effects of the tonal factors can be determined. Special filters can be utilized to study the color films and extract the maximum information on soils and soil conditions. This system would provide excellent information for detailed soils mapping but would require more field exploration and measurements than the optimum system. With this system it is suggested that several passes be made with the IR sensor set at different settings as determined by field radiometer measurements.

Alternates to this system for which costs are less but which require more field investigations - in decreasing order of desirability include:

1. C-P, B-I,IR imagery, simultaneous
2. B&W, B-I, IR imagery simultaneous
3. C-P, C-I,IR imagery concurrent
4. C-P, B-I, IR imagery concurrent
5. B&W, B-I IR imagery, concurrent
6. C-P, IR imagery concurrent.

There is also the possibility of obtaining these systems at different times since it was demonstrated that similar information can be obtained. However, this would require considerably more field control so that changes occurring between flights can be evaluated.

(b) Lack of security clearance would eliminate any possibility of obtaining imagery. This would greatly limit the amount of detailed information that could be interpreted from the data collected. The most desirable systems under these conditions would be the simultaneous procurement of C-P and C-I. Alternates to this system for which costs are less, but which require more field investigation - in decreasing order of desirability include:

1. C-P, B-I, simultaneous
2. C-P, B-I, concurrent


2
8


2
8
7

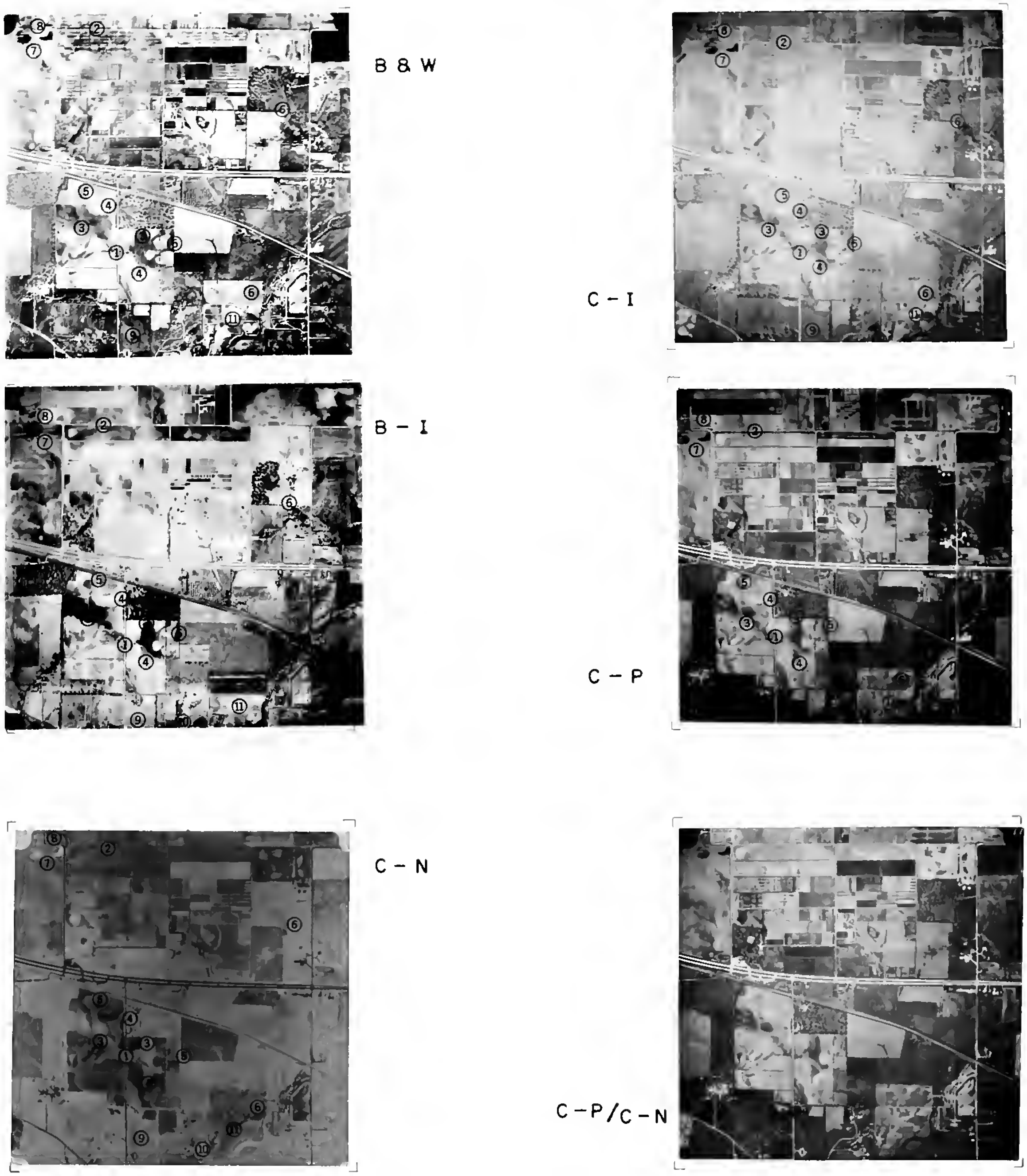


FIGURE 52. COMPARISON OF VARIOUS FILM TYPES (MAY, 1966).

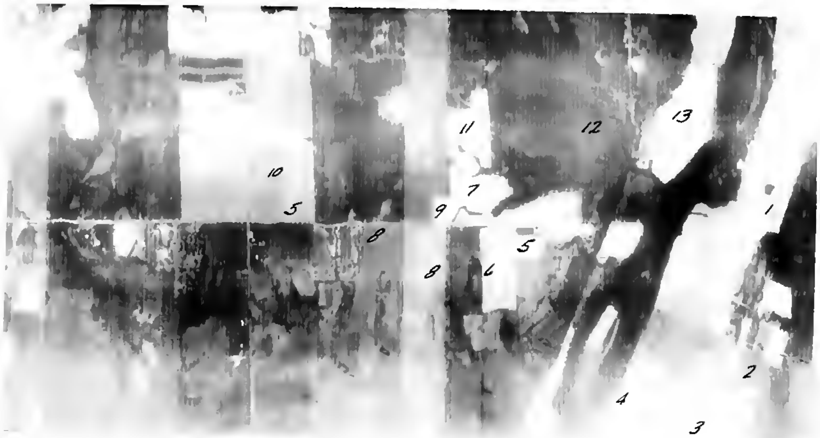
DAYTIME IR

8 - 14μ

DAYTIME IR

8 - 14 μ

(JUNE 2, 1966)



DAYTIME IR

4.5 - 5.5 μ

(JUNE 2, 1966)

B & W PHOTOGRAPHY

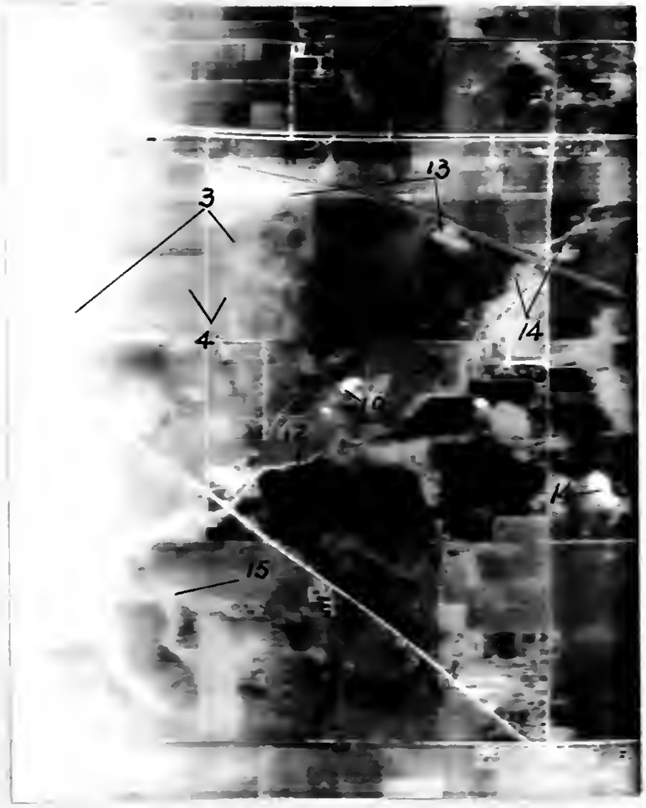
(MAY 2, 1966)

FIGURE 53. COMPARISON OF VISUAL PHOTOGRAPHY AND INFRARED IMAGERY IN 4.5 - 5.5 μ AND 8 - 14 μ BANDS.

DAYTIME IR

8 – 14 μ

(JUNE 2, 1966)

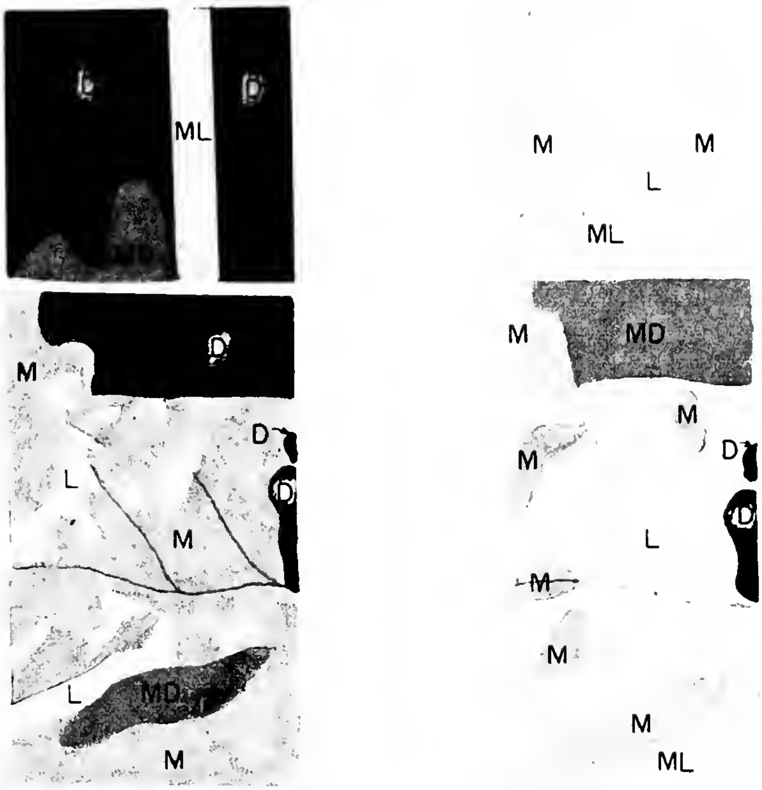


NIGHTTIME IR

8 – 14 μ

(JUNE 1, 1966)

FIGURE 54. COMPARISON OF DAYTIME AND NIGHTTIME INFRARED IMAGERY.



PASS NO. 2
0930 HRS.

PASS NO. 3
0935 HRS.

INFRARED IMAGERY (MAY 13, 1965)
"ARTIST SKETCH"

TONES:

L	LIGHT
ML	MEDIUM LIGHT
M	MEDIUM
MD	MEDIUM DARK
D	DARK

FIGURE 55. EFFECT OF INSTRUMENT SETTING ON INFRARED TONAL PATTERNS.

HH RADAR
(SEPT. 14, 1965)

HV RADAR
(SEPT. 14, 1965)

B&W PHOTOGRAPHY
(SEPT. 1, 1965)

FIGURE 56. COMPARISON OF VISUAL PHOTOGRAPHY AND HH AND HV RADAR IMAGERY.

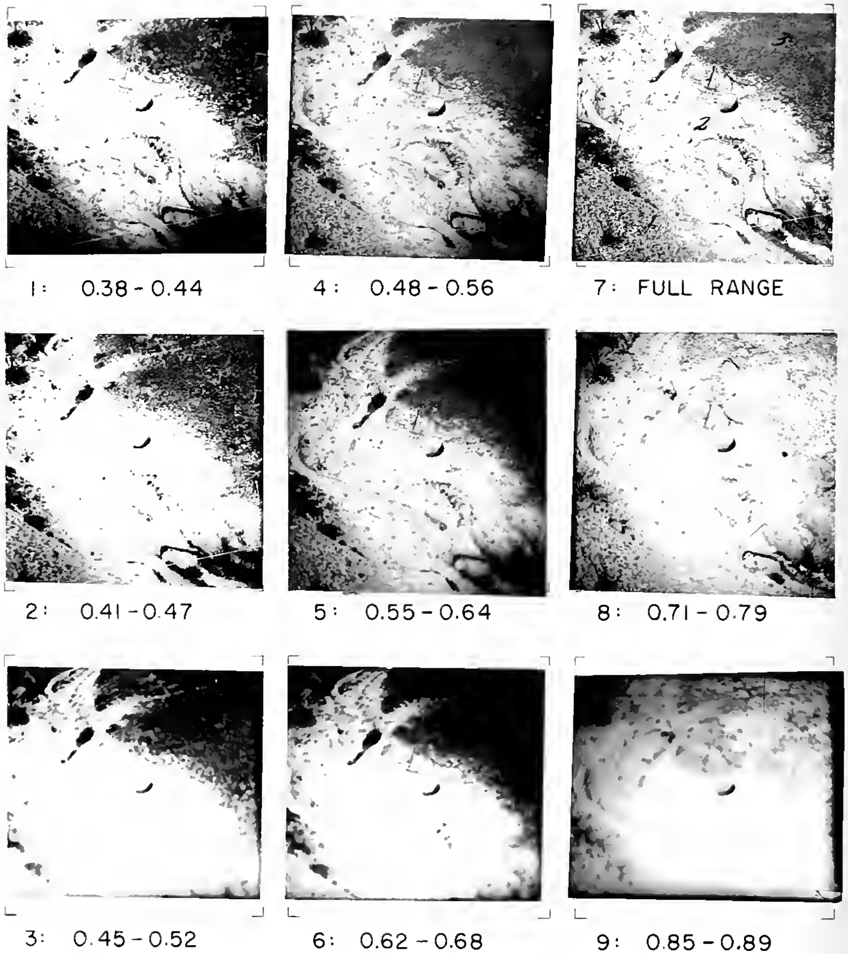
1: 0.

2: 0.

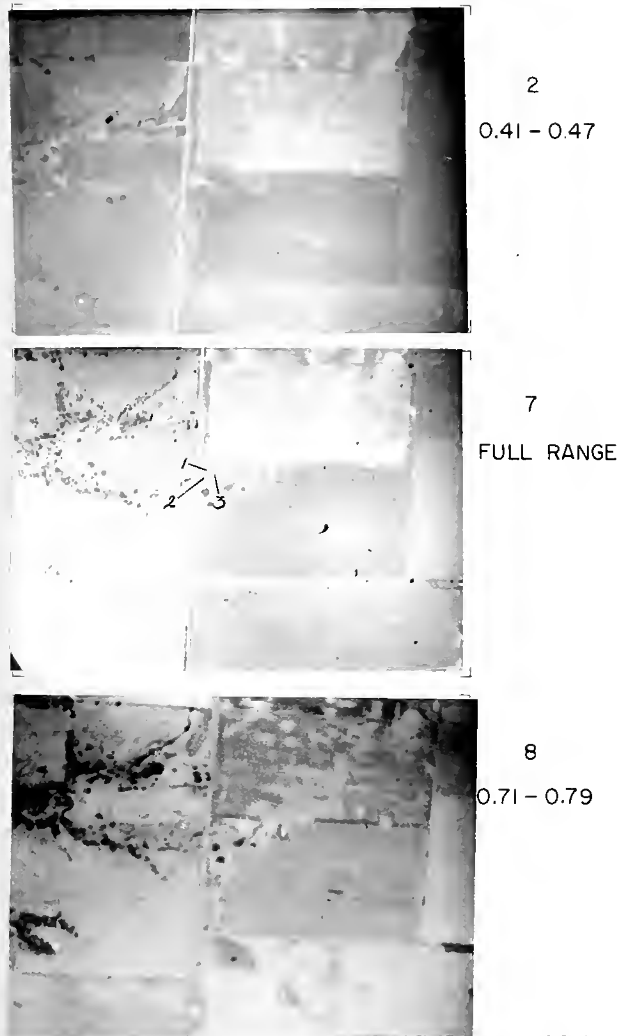
3: 0.

(a) NI

FIGURE

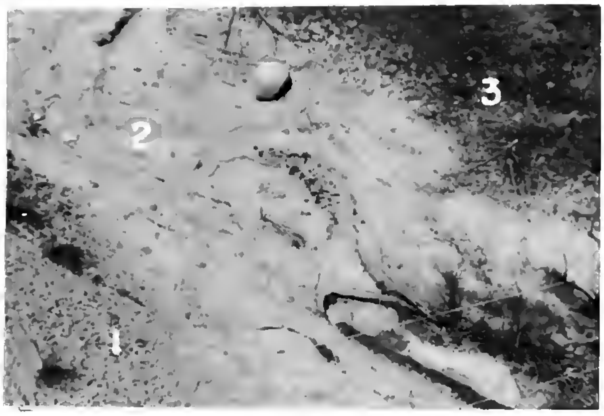


(a) NINE-LENS GROUND PHOTOGRAPH



(b) SELECTED BANDS-AERIAL PHOTOGRAPH

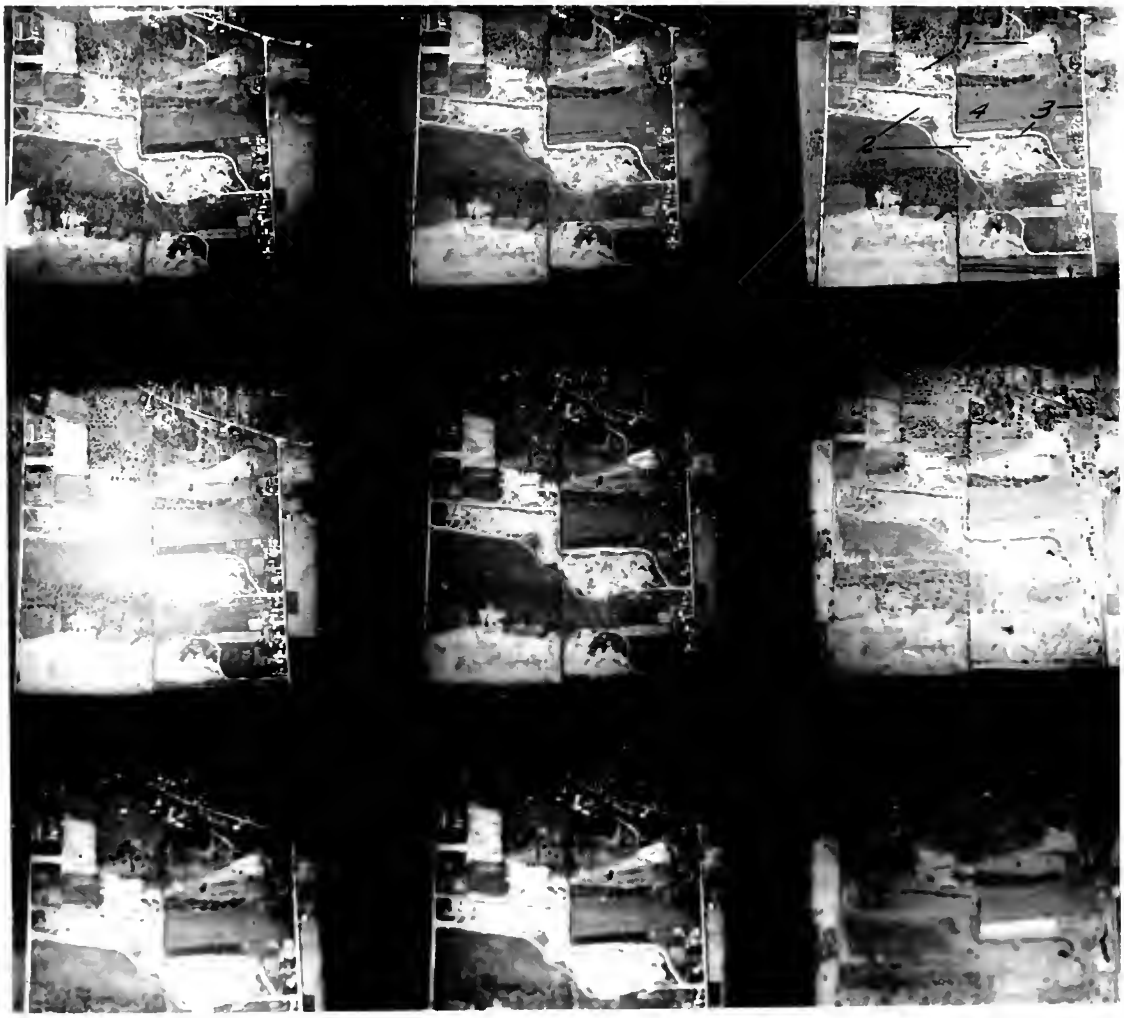
FIGURE 57. COMPARISON OF GROUND AND SELECTED AERIAL NINE-LENS PHOTOGRAPHS.



(a) GROUND PHOTOGRAPH

(b) AERIAL PHOTOGRAPH

FIGURE 58. GROUND AND AERIAL COLOR PHOTOGRAPHS OF NINE-LENS TEST SITE.



BANDS:

1: 0.38 - 0.44	4: 0.48 - 0.56	7: FULL RANGE
2: 0.41 - 0.47	5: 0.55 - 0.64	8: 0.71 - 0.79
3: 0.45 - 0.52	6: 0.62 - 0.68	9: 0.85 - 0.89

FIGURE 59. NINE-LENS PHOTOGRAPH DEMONSTRATING TONAL RELATIONSHIPS OF COARSE-TEXTURED SOILS.

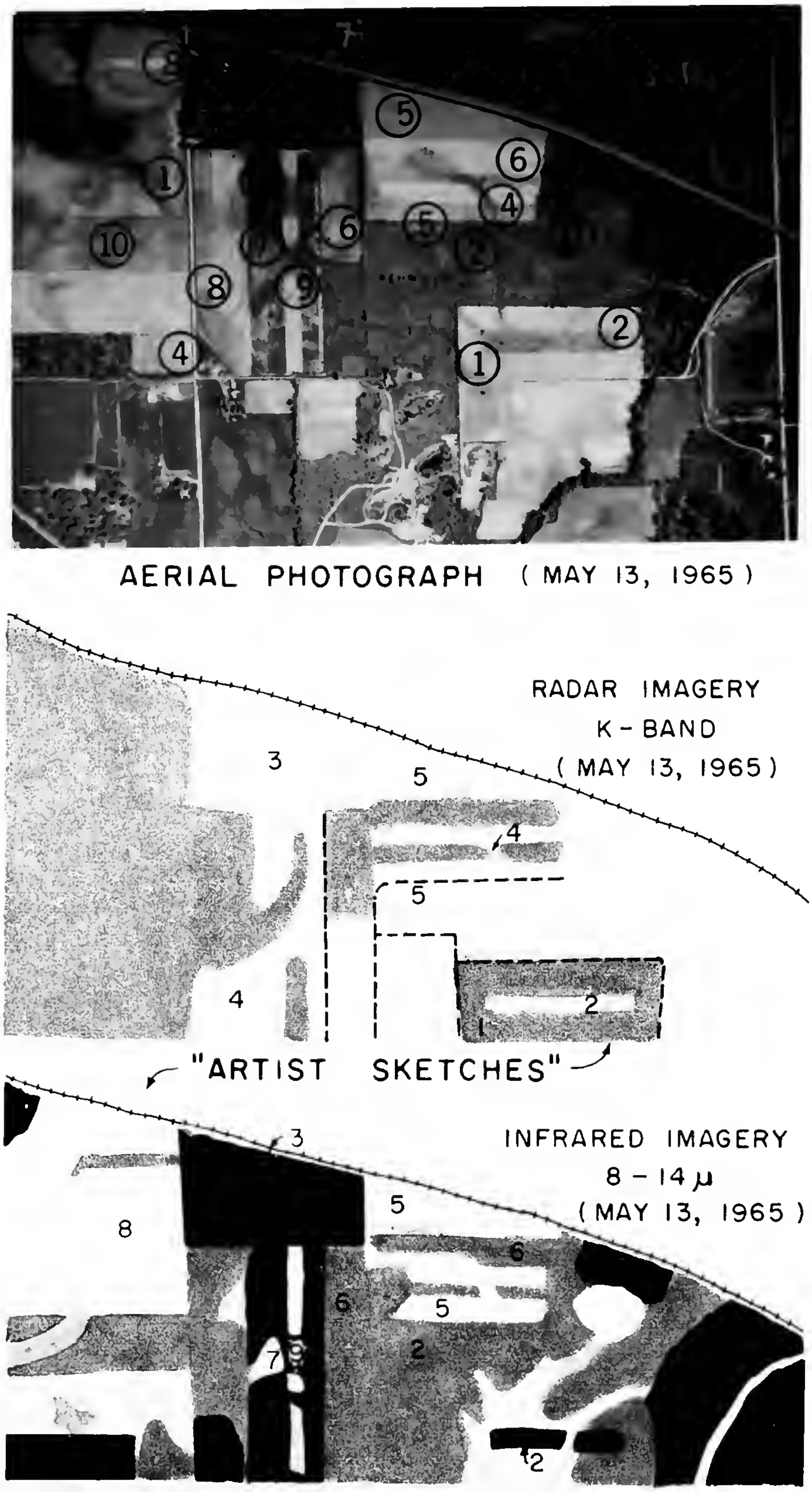
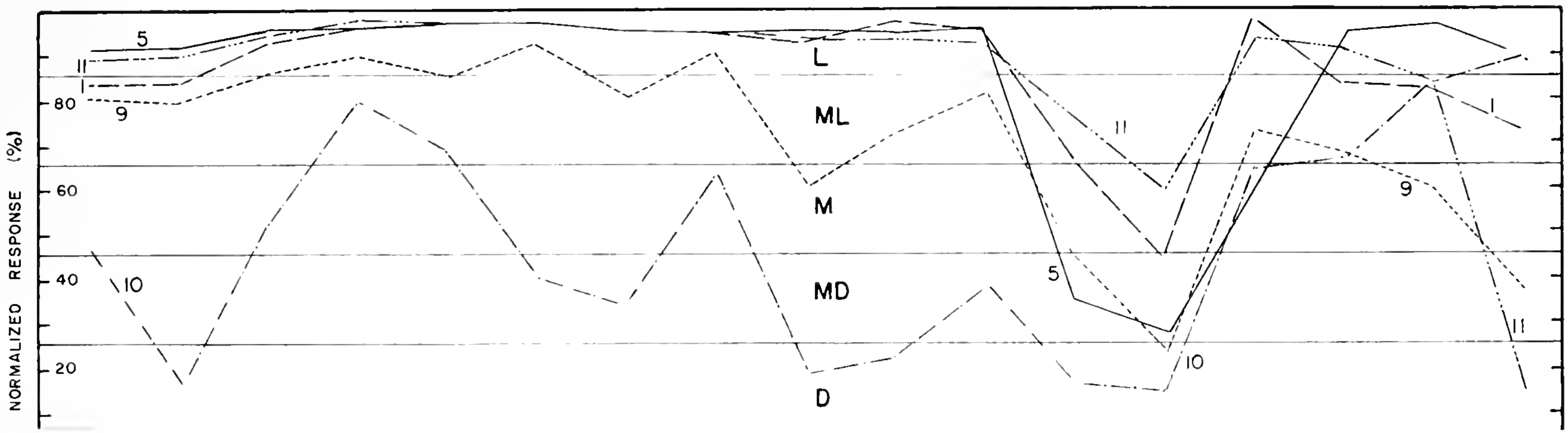


FIGURE 60. COMPARISON OF MULTISENSOR PHOTOGRAPHY AND IMAGERY.

B & W MOSAIC (MAY 6, 1966)

POINT	SOIL OR ROCK UNIT	CONDITION
1.	THICK LOESS/GLACIAL TILL	HIGH POSITION - BARE
2.	GLACIAL TILL	HIGH POSITION – PLOWING IN PROGRESS
3.	GLACIAL TILL	HIGH POSITION – RECENTLY PLOWED
4.	GLACIAL TILL	HIGH POSITION - PLOWED A FEW DAYS AGO
5.	SANDSTONE	SMALL EXPOSURE
6	GLACIAL TILL	COVERED WITH WINTER WHEAT
7.	GLACIAL TILL/SANDSTONE	PASTURE, SANDSTONE EXPOSED IN PLACES
8.	GLACIAL TILL/SANDSTONE	PASTURE
9.	GLACIAL TILL	HIGH POSITION
10.	GLACIAL TILL	DEPRESSION
11.	GLACIAL TILL	HIGH POSITION
12.	GLACIAL TILL	COVERED WITH WINTER WHEAT
13.	FLOOD PLAIN	PLOWING IN PROGRESS
14.	FLOOD PLAIN	RECENTLY PLOWED
15.	SAND DUNES	BARE IN PLACES

FIGURE 61. LOCATION OF POINTS MEASURED ON MULTICHANNEL IMAGERY.



NORMALIZED RESPONSE (%)
80
60
40
20
L
ML
M
MD
D
5
11
1
9
10

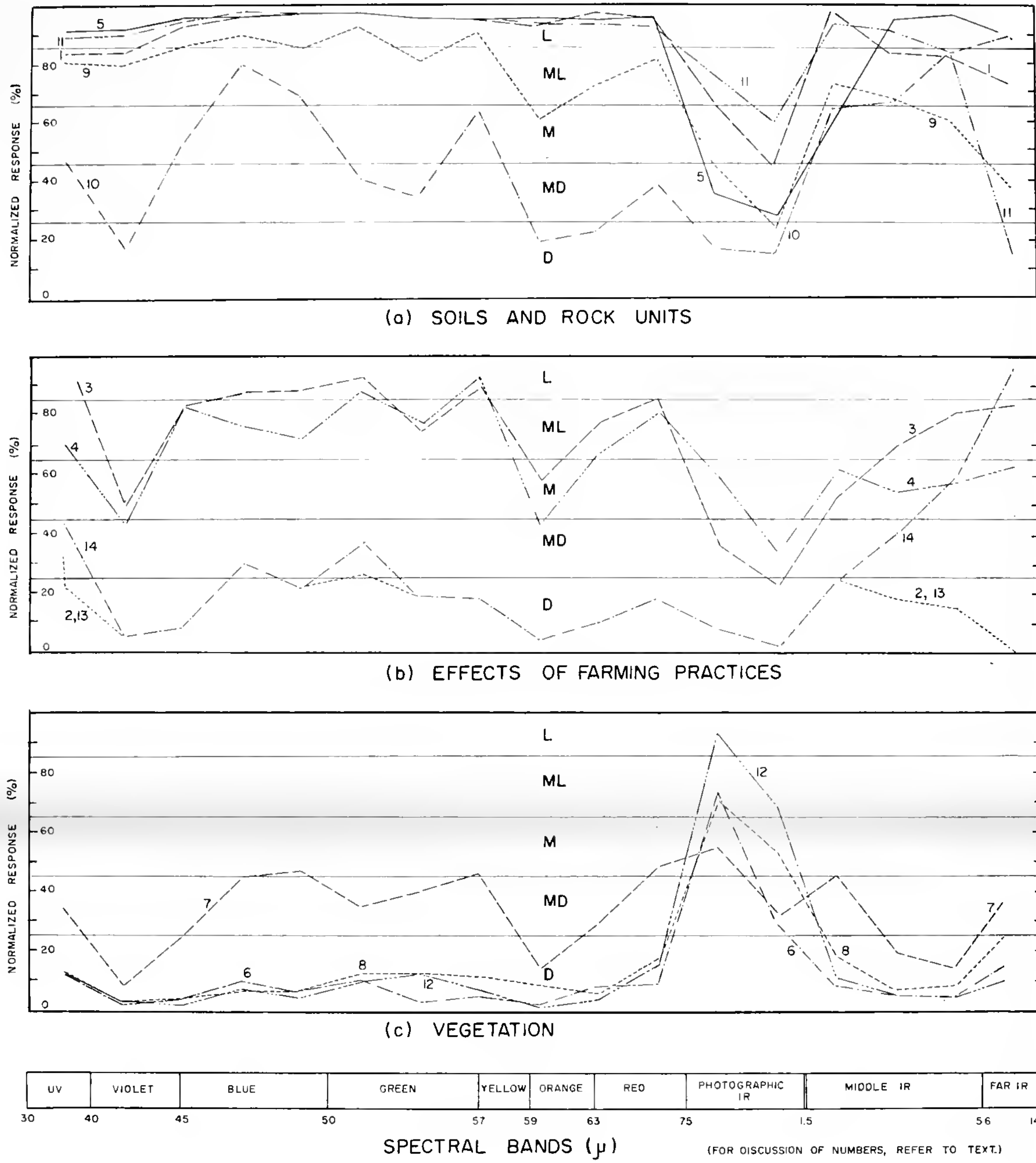


FIGURE 62. SPECTRAL RESPONSE SIGNATURES FOR VARIOUS TARGET MATERIALS

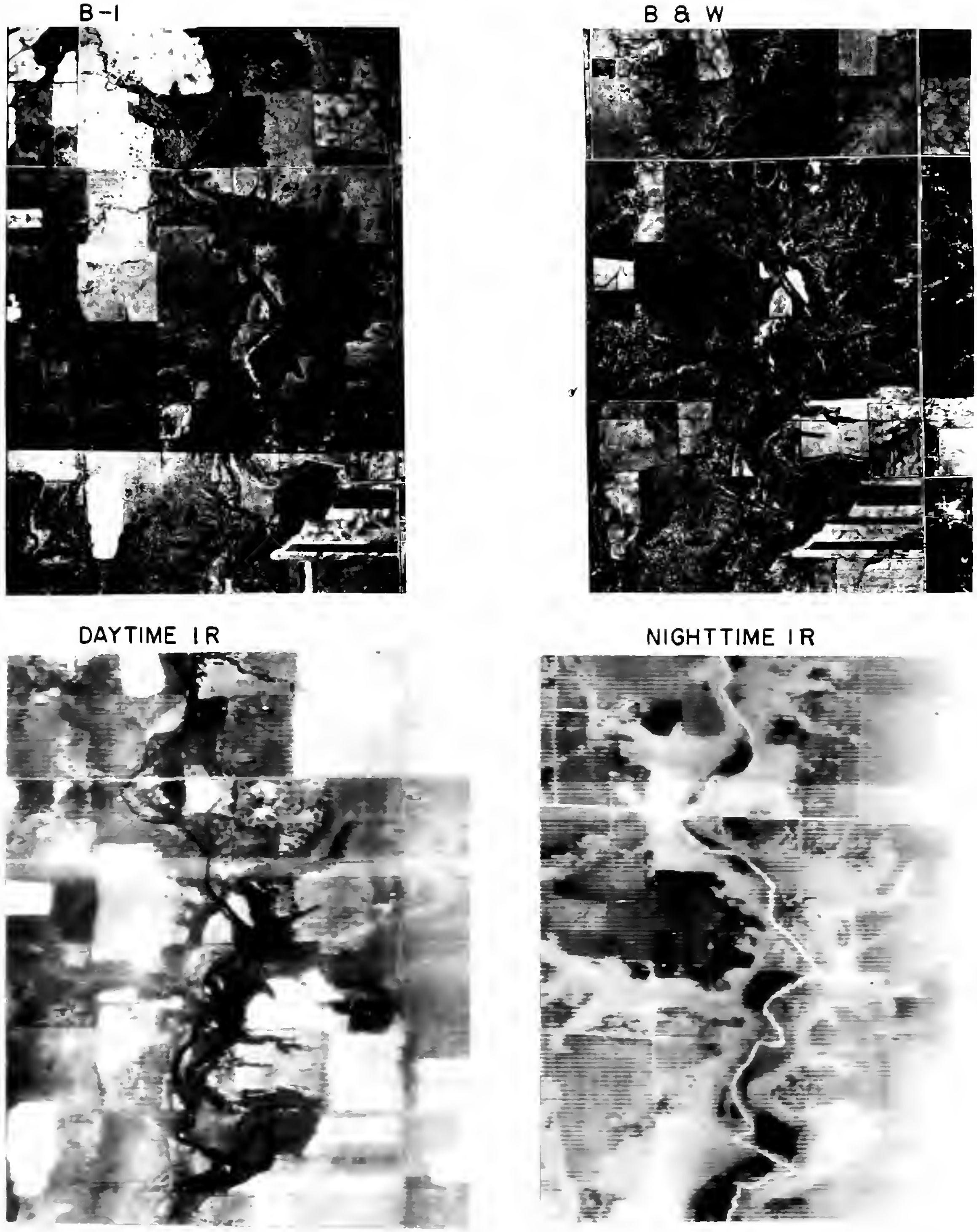
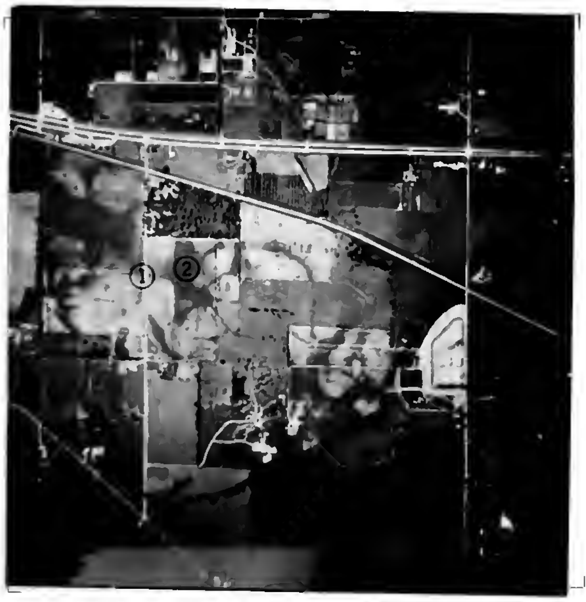


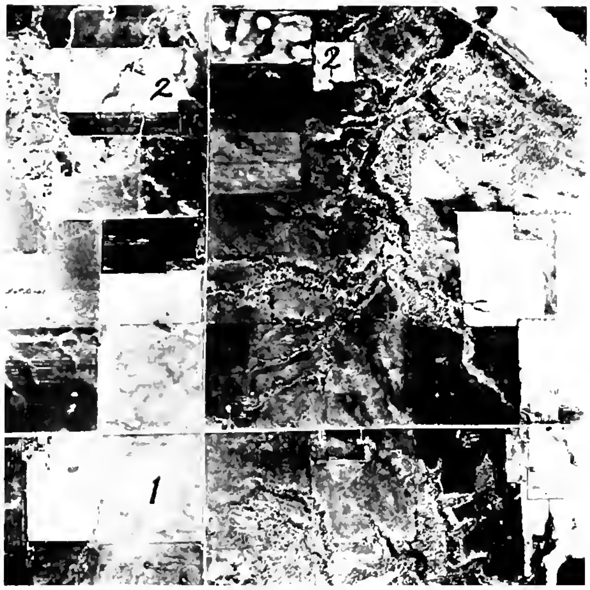
FIGURE 63. COMPARISON OF DRAINAGE PATTERNS EVIDENT ON PHOTOGRAPHY AND IR IMAGERY.



C – P (JULY 26, 1966)

C – P (OCT. 25–26, 1966)

FIGURE 64. INFLUENCE OF SEASON OF YEAR ON SOIL ANALYSIS.



B & W (MAY 2, 1966)

B & W/C-N (MAY 3, 1966)

FIGURE 65. VARIATIONS DUE TO TIME FACTOR.

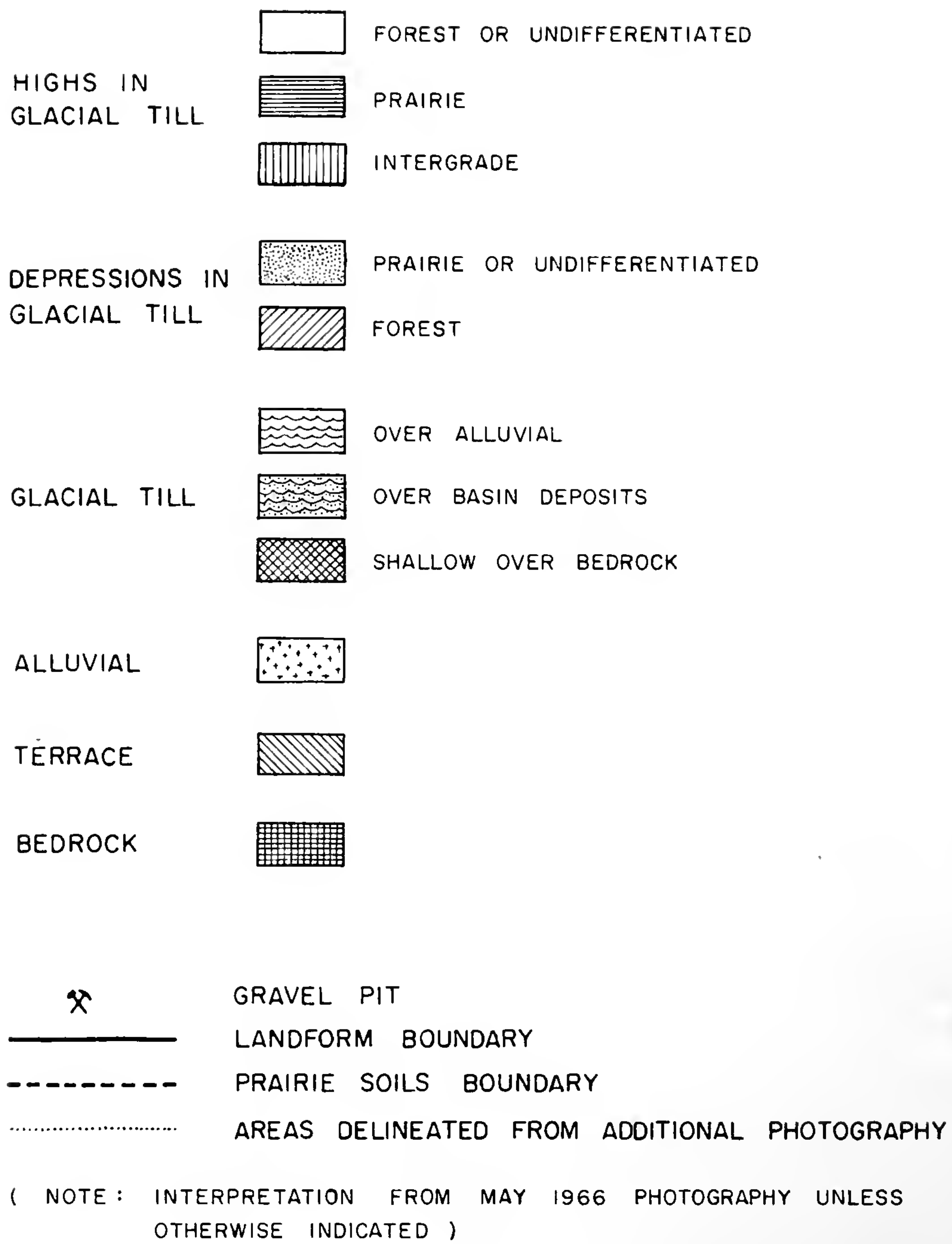
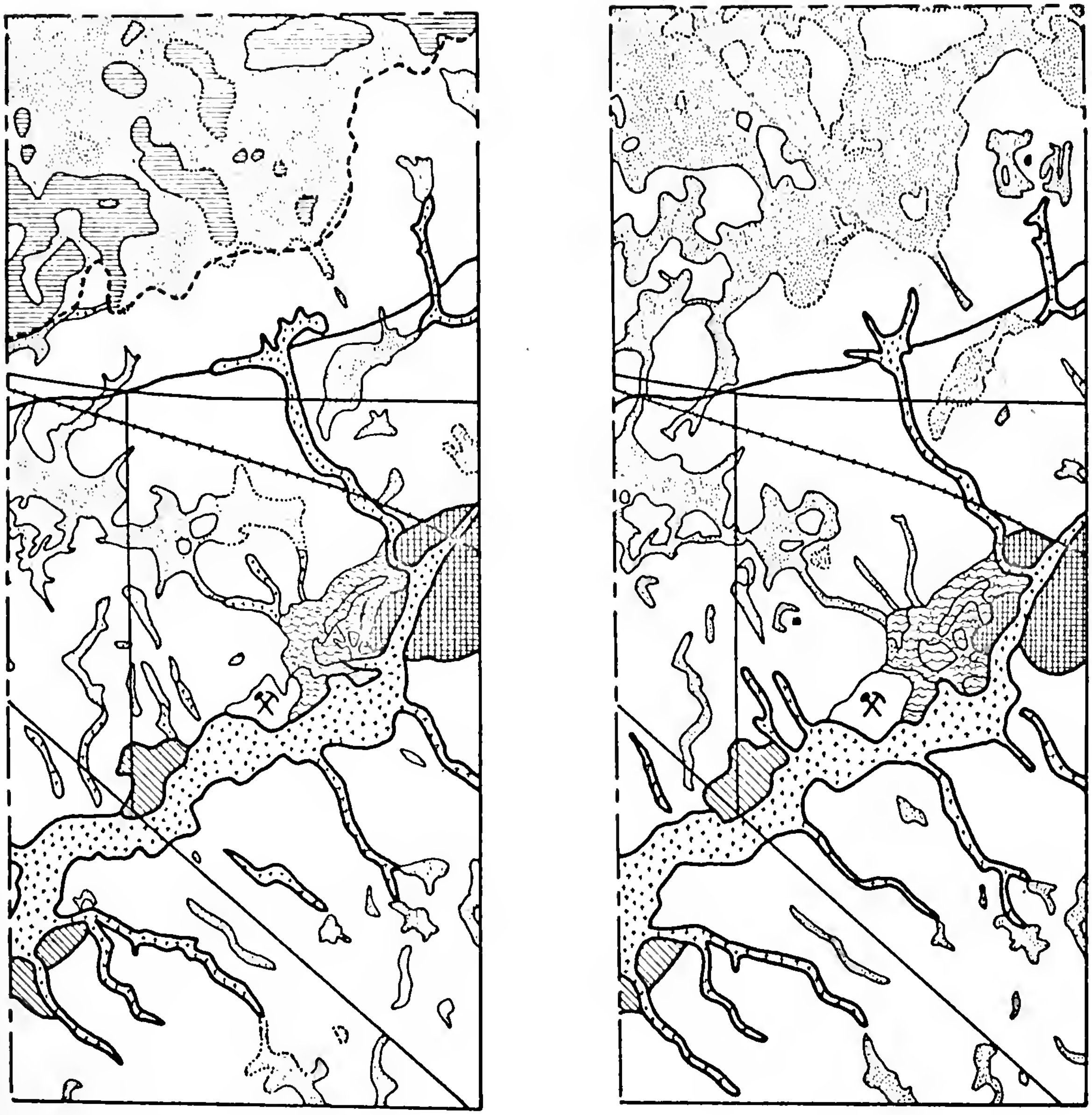


FIGURE 66. LEGEND FOR FIGURES 67, 68, AND 69.



(a) COLOR PHOTOGRAPHY
(ORIGINAL SCALE 1 : 10,000)

(b) BLACK-AND-WHITE PHOTOGRAPHY
(ORIGINAL SCALE 1 : 10,000)

SCALE 1 : 24,000

FIGURE 67. COMPARISON OF ENGINEERING SOILS MAPS PREPARED FROM COLOR AND BLACK-AND-WHITE PHOTOGRAPHY

HIGHS IN GLACIAL TILL
- FOREST OR UNDIFFERENTIATED
- PRAIRIE
- INTERGRADE

DEPRESSIONS IN GLACIAL TILL
- PRAIRIE OR UNDIFFERENTIATED
- FOREST

GLACIAL TILL
- OVER ALLUVIAL
- OVER BASIN DEPOSITS
- SHALLOW OVER BEDROCK

ALLUVIAL

TERRACE

BEDROCK

GRAVEL PIT

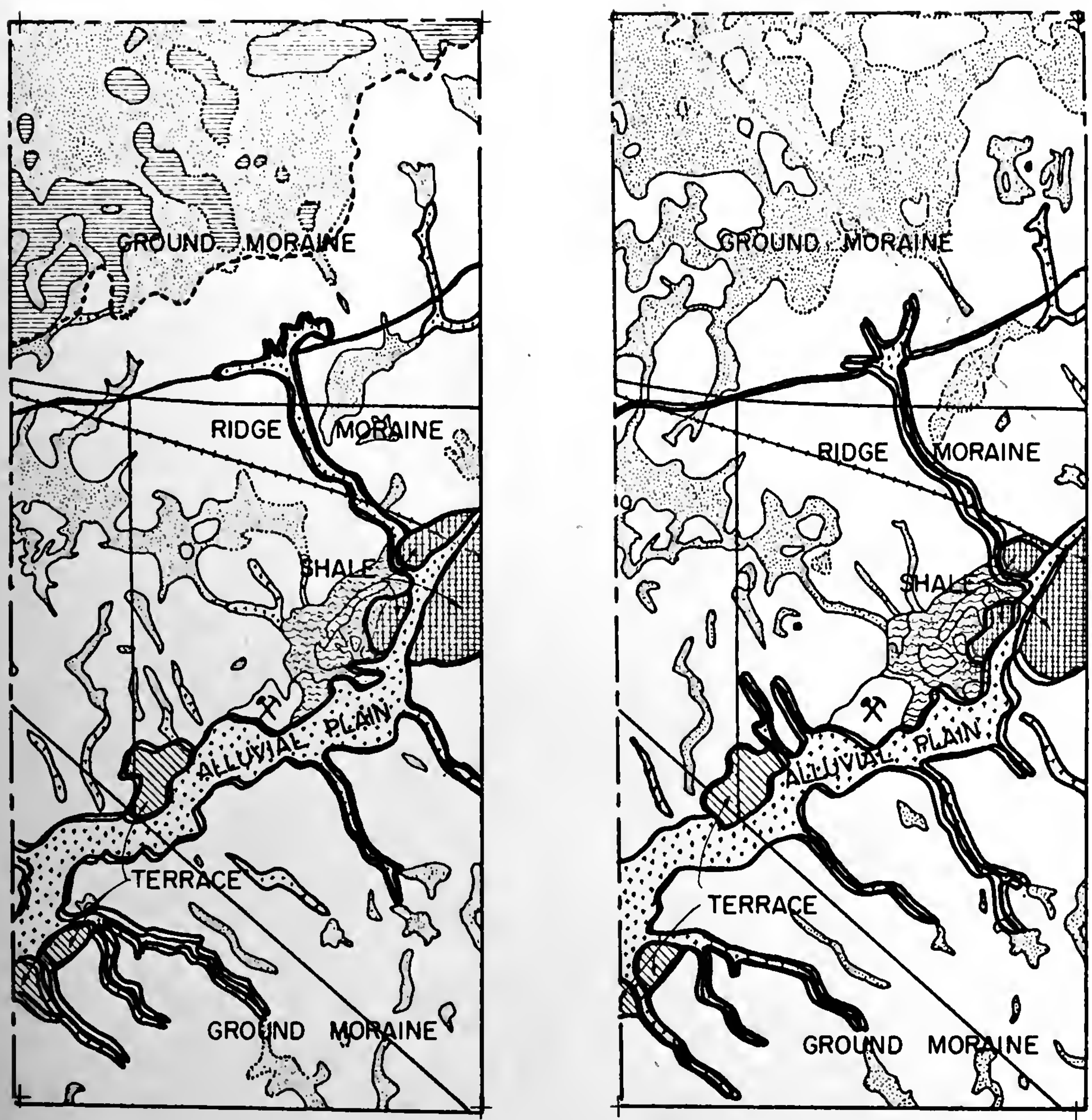
LANDFORM BOUNDARY

PRAIRIE SOILS BOUNDARY

AREAS DELINEATED FROM ADDITIONAL PHOTOGRAPHY

(NOTE : INTERPRETATION FROM MAY 1966 PHOTOGRAPHY UNLESS OTHERWISE INDICATED)

FIGURE 66. LEGEND FOR FIGURES 67, 68, AND 69.



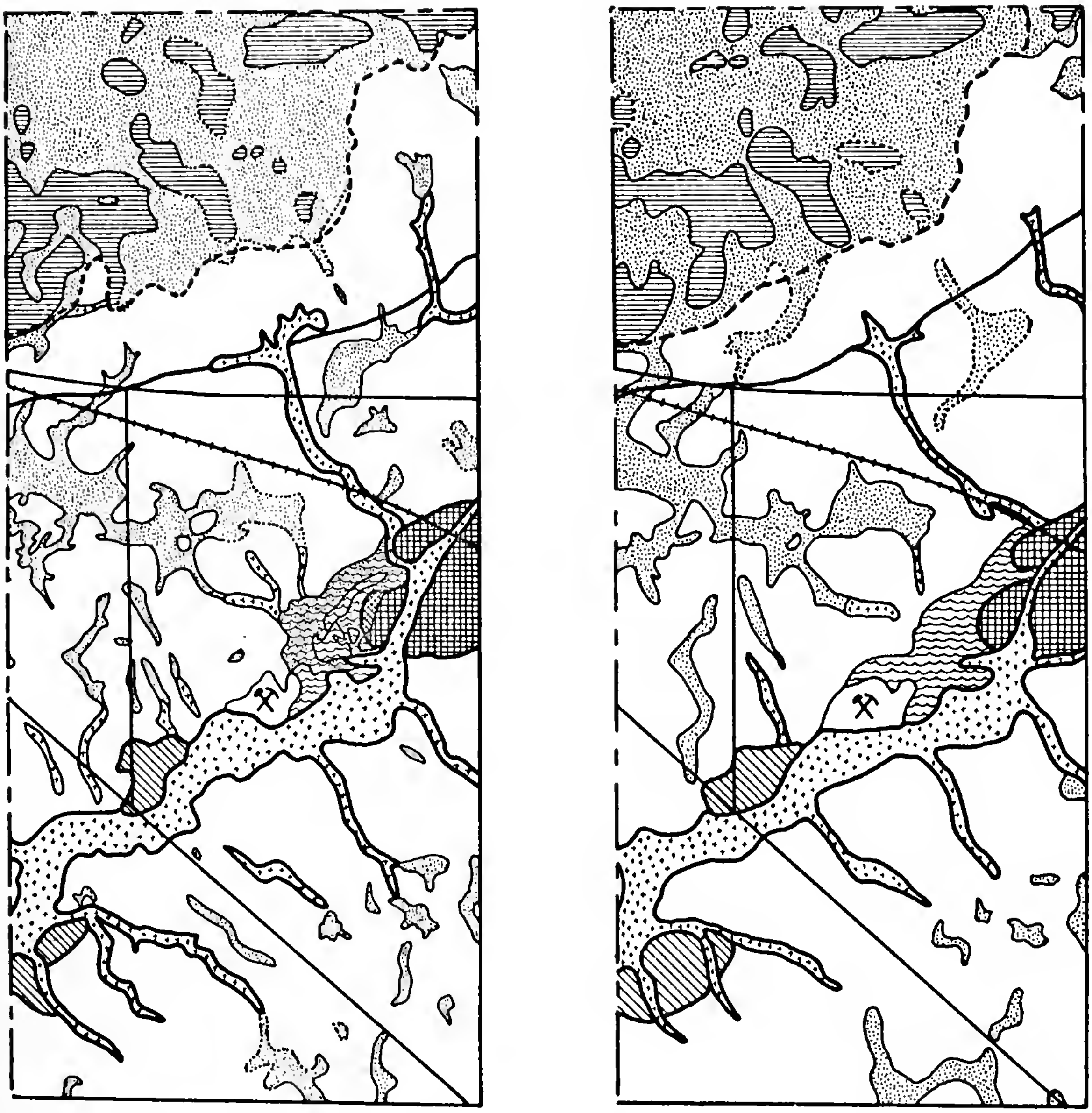
(a) COLOR PHOTOGRAPHY
(ORIGINAL SCALE 1 : 10,000)

(b) BLACK-AND-WHITE PHOTOGRAPHY
(ORIGINAL SCALE 1 : 10,000)

SCALE 1 : 24,000

FIGURE 67.

FIGURE 67. COMPARISON OF ENGINEERING SOILS MAPS PREPARED FROM COLOR AND BLACK-AND-WHITE PHOTOGRAPHY.

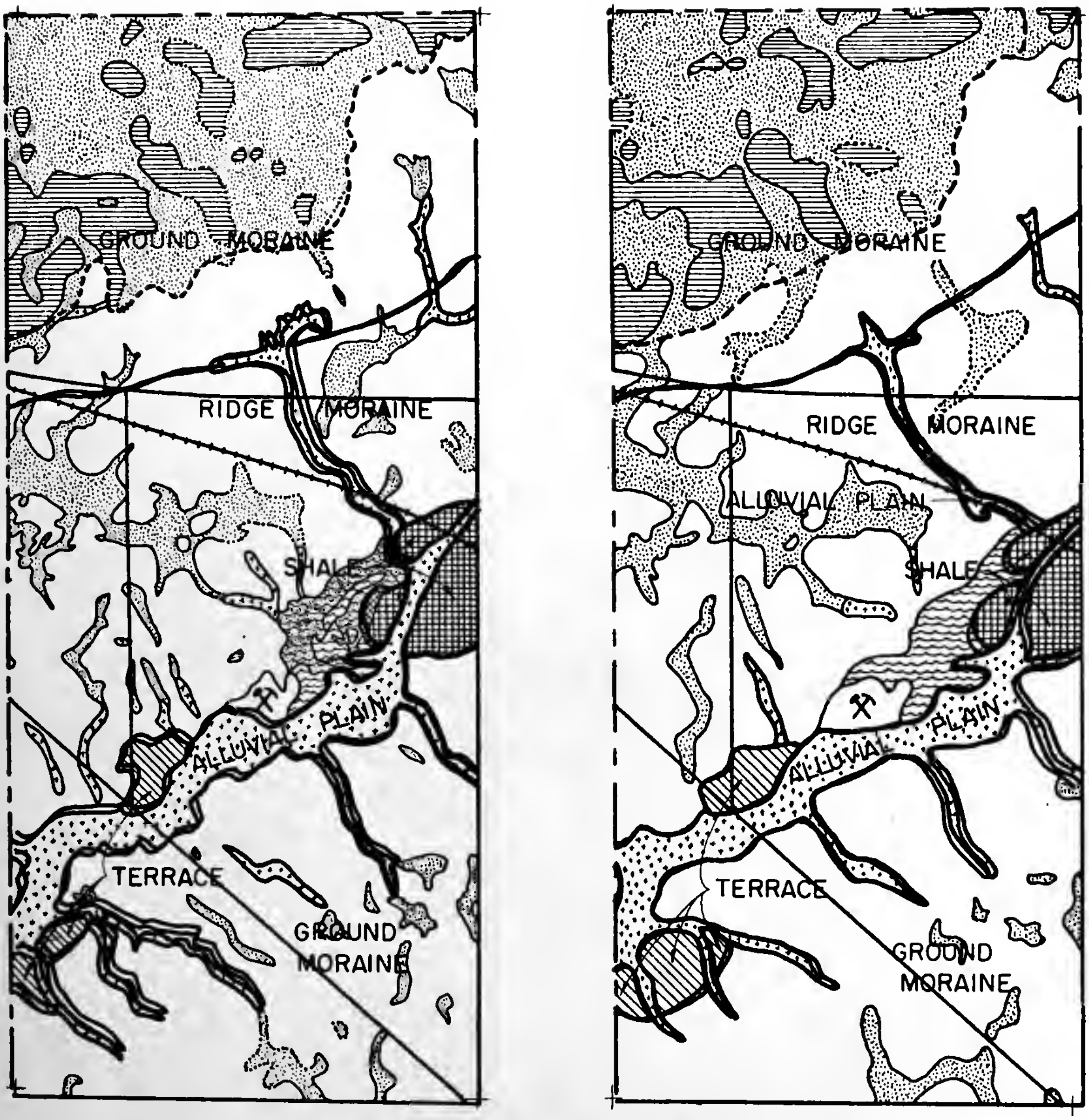


(a) COLOR PHOTOGRAPHY
(ORIGINAL SCALE 1 : 10,000)

(b) COLOR PHOTOGRAPHY
(ORIGINAL SCALE 1 : 24,000)

SCALE 1 : 24,000

FIGURE 68. COMPARISON OF ENGINEERING SOILS MAPS PREPARED FROM COLOR PHOTOGRAPHY AT TWO DIFFERENT SCALES.



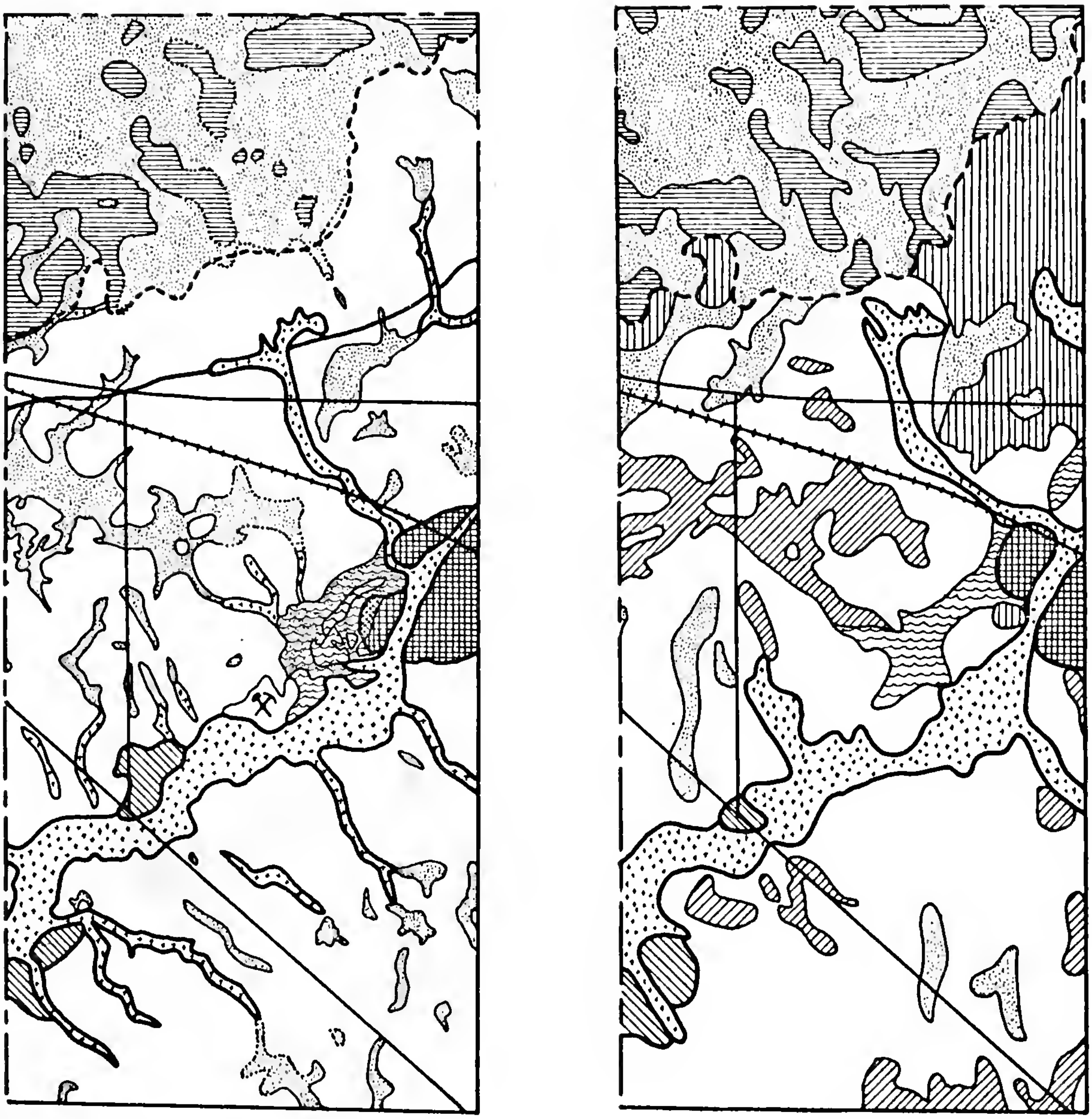
(a) COLOR PHOTOGRAPHY
(ORIGINAL SCALE 1 : 10,000)

(b) COLOR PHOTOGRAPHY
(ORIGINAL SCALE 1 : 24,000)

SCALE 1 : 24,000

FIGURE 68.

FIGURE 68. COMPARISON OF ENGINEERING SOILS MAPS PREPARED FROM COLOR PHOTOGRAPHY AT TWO DIFFERENT SCALES.

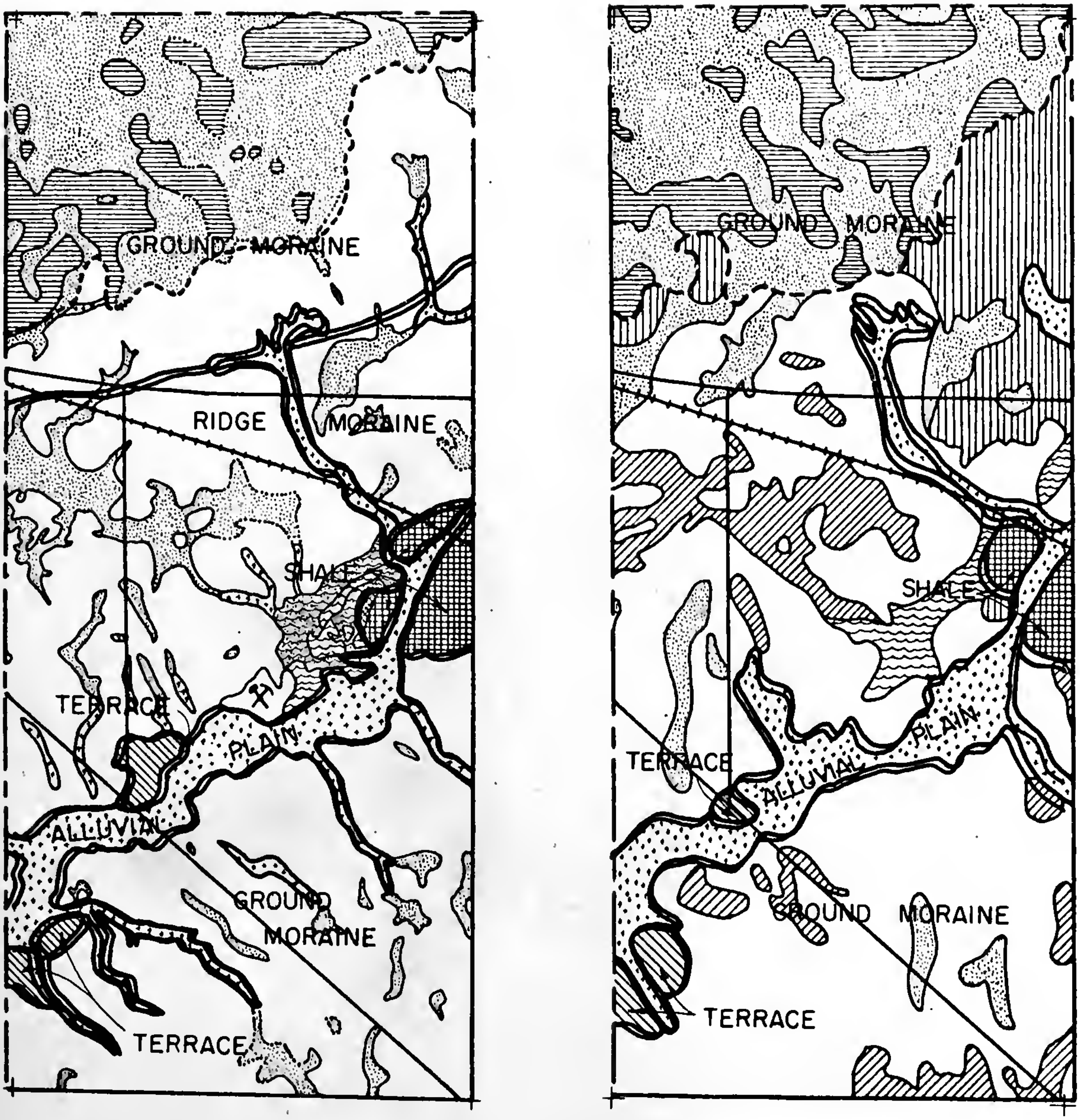


(a) COLOR PHOTOGRAPHY
(ORIGINAL SCALE 1 : 10,000)

(b) PREPARED FROM AGRICULTURAL SOIL SURVEY MAP
(ORIGINAL SCALE 1 : 31,680)

SCALE 1 : 24,000

FIGURE 69. COMPARISON OF ENGINEERING SOILS MAPS PREPARED FROM COLOR PHOTOGRAPHY AND AGRICULTURAL SOIL SURVEY MAP.



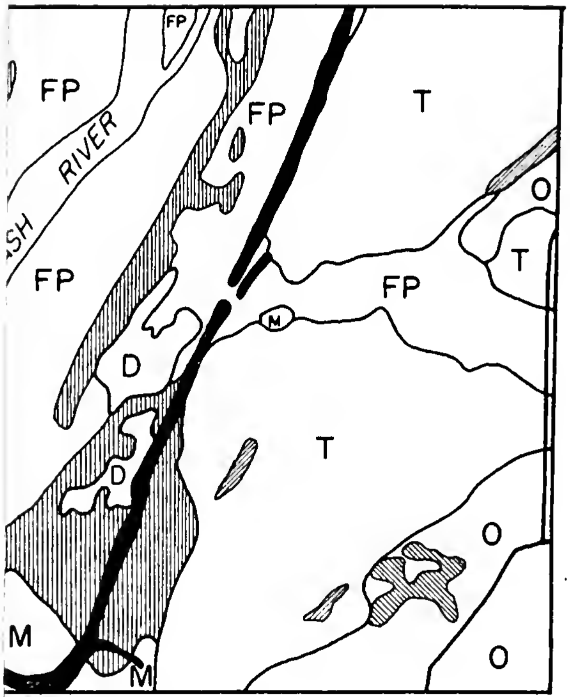
(a) COLOR PHOTOGRAPHY
(ORIGINAL SCALE 1 : 10,000)

(b) PREPARED FROM AGRICULTURAL SOIL SURVEY MAP
(ORIGINAL SCALE 1 : 31,680)

SCALE 1 : 24,000

FIGURE 69.

FIGURE 69. COMPARISON OF ENGINEERING SOILS MAPS PREPARED FROM COLOR PHOTOGRAPHY AND AGRICULTURAL SOIL SURVEY MAP.



CONSOLIDATED:

— INTERBEDDED SEDIMENTARY ROCKS (UNDIFFERENTIATED)

s — SANDSTONE

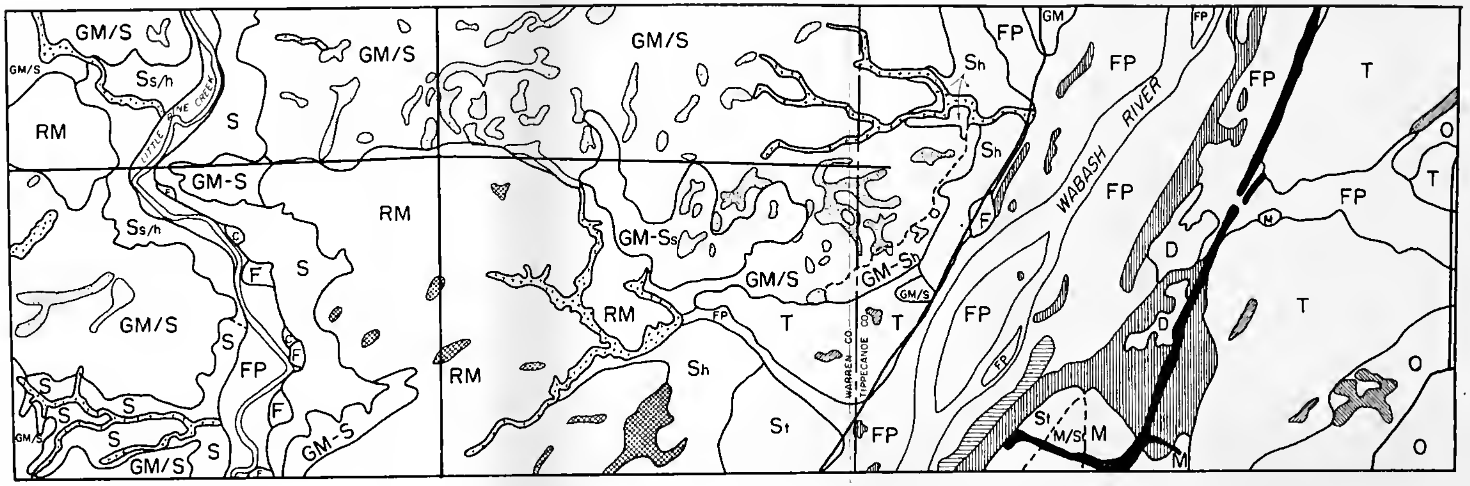
h — SHALE

s/h— SANDSTONE OVER SHALE

t — BEDROCK TERRACE

E APPROXIMATELY 1 : 20,000

SITE III.



LEGEND:

UNCONSOLIDATED:

FP – FLOOD PLAINS (MAJOR DRAINAGE WAYS)
- MINOR DRAINAGE WAYS
- SWALES AND DEPRESSIONS
- NATURAL LEVEES

O – OUTWASH PLAIN
- DEPRESSIONS

T – TERRACE
- SWALES

M – ORGANIC DEPOSITS (MUCK & PEAT)

M/S – ORGANIC DEPOSITS OVER SEDIMENTARY ROCKS
- MAN MADE FILL

GM – GROUND MORAINE
- DEPRESSIONS

GM-S – GROUND MORAINE OVER SEDIMENTARY ROCK (BEDROCK WITHIN 5 FEET)

GM/S – GROUND MORAINE OVER SEDIMENTARY ROCK (BEDROCK WITHIN 5 - 15 FEET)

RM – RIDGE MORAINE
- DEPRESSIONS

D – SAND DUNES

F – ALLUVIAL FANS

C – COLLUVIAL DEPOSITS

CONSOLIDATED:

S – INTERBEDDED SEDIMENTARY ROCKS (UNDIFFERENTIATED)

Ss – SANDSTONE

Sh – SHALE

Ss/h – SANDSTONE OVER SHALE

St – BEDROCK TERRACE

SCALE APPROXIMATELY 1 : 20,000

FIGURE 70. DETAILED ENGINEERING SOILS MAP OF A PORTION OF SITE III.

FIGURE 71.

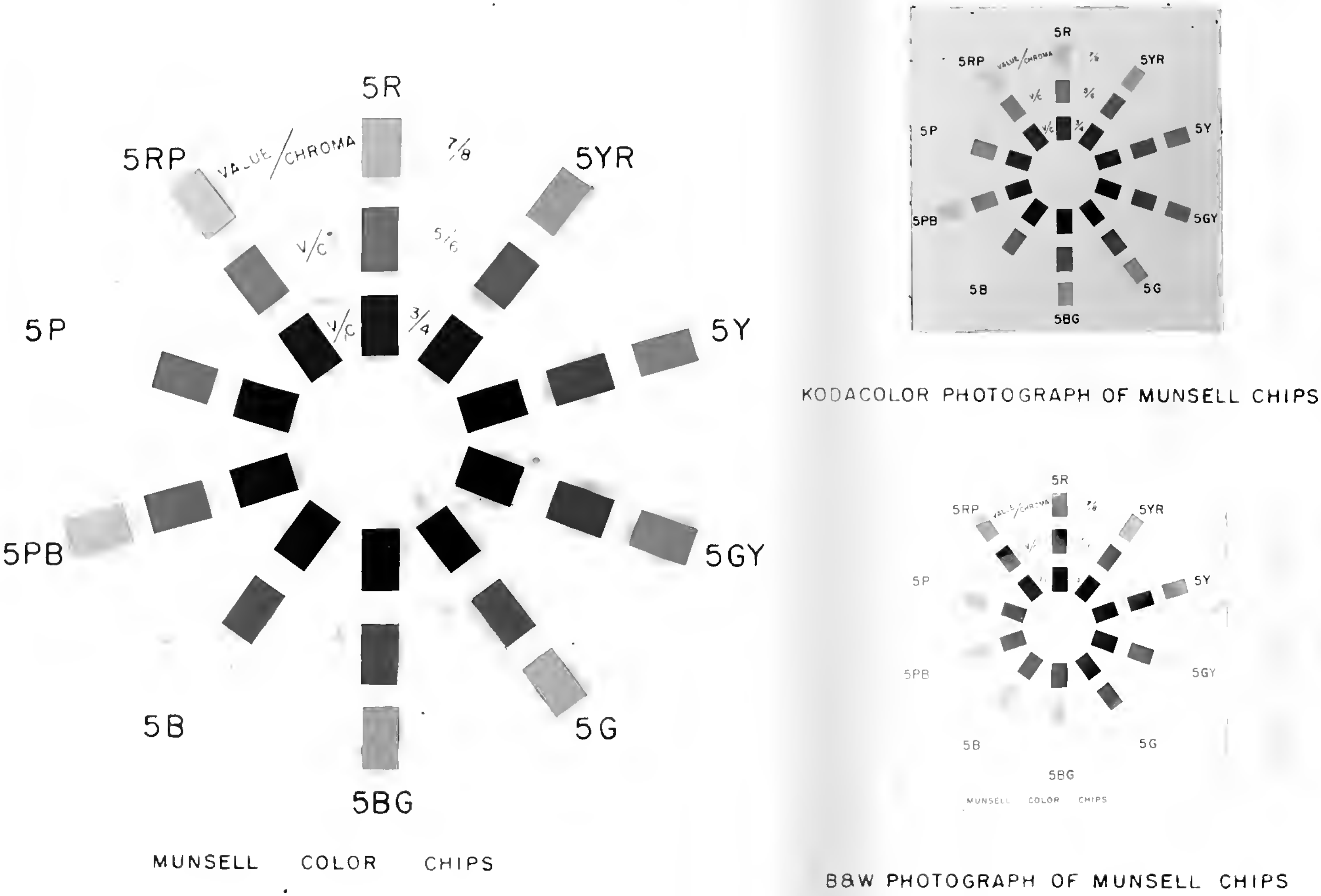


FIGURE 71. COMPARISON OF COLOR AND B&W PRINTS TO ORIGINAL MUNSELL COLOR CHIPS.

CHAPTER 6

QUANTITATIVE MEASUREMENTS ON PHOTOGRAPHY AND IMAGERY

Introduction

The purposes of this phase of the research project were to investigate the value of quantitative measurements on aerial photography and imagery to determine their usefulness in the interpretation of soils information and in preparing detailed soils maps. Several approaches were attempted. These include:

1. Performance of continuous densitometric scans to determine whether typical signatures existed for the various land forms encountered;

2. Preparation of "isotonal" maps to determine whether areas of similar soil conditions could be delineated based on differences in reflection or transmission density;

3. Development of a simple, automatic technique for identifying and separating the various colors on color aerial photography to assist in accomplishing the goals of items 1 and 2 and in describing colors on color photography.

All of these approaches were attempts at establishing an automatic interpretation technique for the identification of land forms and possibly also the delineations of various types of engineering soils groups.

An additional quantitative technique investigated was the determination of spectral response signatures for various target materials.

Because of differences in scale, format and resolution between the various film and imagery types, this approach was only attempted for the multichannel data where these factors were the same in all channels. This item was discussed in the previous chapter (page 259).

The various quantitative measurements were obtained with a reflection (RD-100) and transmission (TD-102) densitometer as discussed in Chapter 4 (commencing on page 196).

Continuous Densitometer Scans

To determine whether typical reflection densitometric patterns could be obtained for the various land forms encountered, continuous densitometric scans were performed on uncontrolled B&W mosaics of the three test sites. Three scan lines were made on each mosaic. An example of the uncontrolled mosaic for Site I and the continuous scans obtained are shown in Figure 72. Only the major land forms north of the river are shown on the mosaic. The boundary lines for these land forms are also shown on the individual scans.

Unique densitometer scan patterns could not be developed for any of the land forms in this site or the other sites. As noted in Figure 72 there are more variations within land forms than between some of the land forms. For example, similar highly irregular scan patterns were obtained in the sand dunes (SD) (Scan 2, zone A) as were obtained for the housing development in the ground moraine (GM) (Scan 2, zone B, Scan 1, zone C). Comparison of the three scans in the ground moraine areas indicate no similarity of patterns. This example demonstrates that the variability existing in the scans can more easily be related to variations in tones on the photography which are produced by the tonal

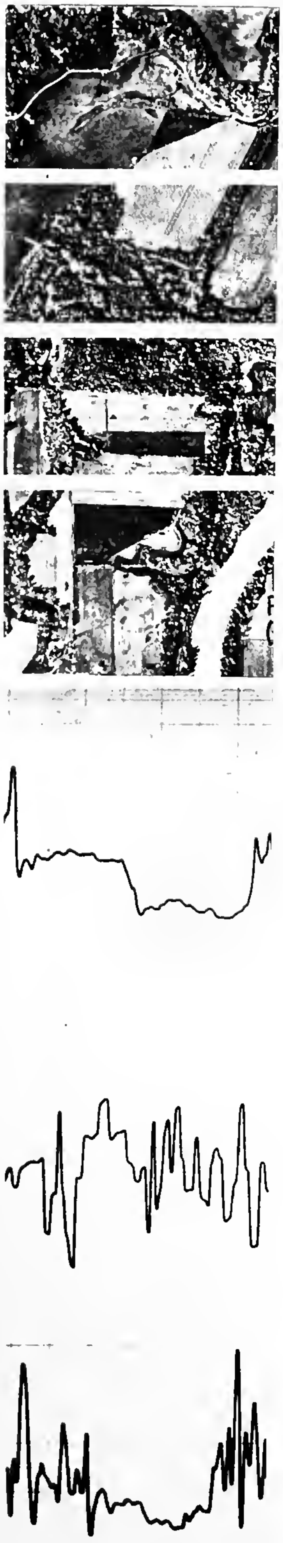


FIGURE 72. C(

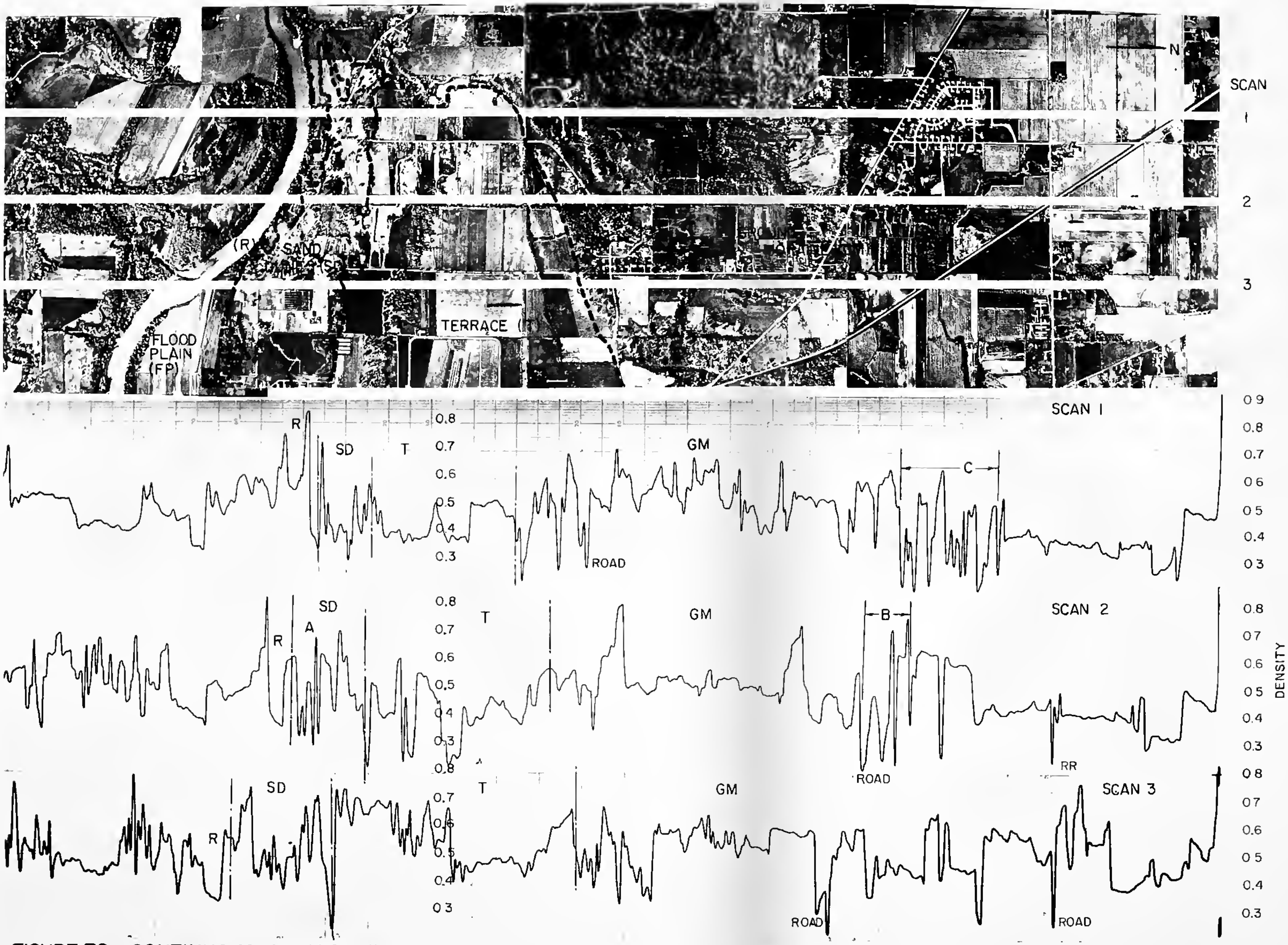


FIGURE 72. CONTINUOUS DENSITOMETER SCANS OF UNCONTROLLED MOSAIC OF SITE I.

factors (i.e., culture, vegetation, moisture, intrinsic soil color and type of soil) than to variations in land forms.

Various other parameters have been noted to cause variations in the densitometer scans including: (1) differences due to film types; (2) differences due to type of filter utilized for scanning; (3) season of the photography; (4) aperture size of densitometer; and (5) scale of photography. To evaluate differences occurring due to these items, a test strip in Site III was chosen where a variety of surface conditions existed as shown in Figure 73. The three scan lines chosen for study on the various film types are included within the dotted white bands shown on the photograph. For the final detailed comparisons, the middle band (scan 2) was used. The reference points listed on scan 2 in the figure refer to the various features compared between photographs or used to obtain proper alignment of the scans on the various photographs. These same reference points will be used in all subsequent comparisons where applicable.

The three scans shown on this figure indicate that the scan pattern obtained is a function of the tonal factors. Note the variability of Field E on scans two and three and within each scan. These are directly related to the various tones present in the bare field. The dark depressional areas have high reflection densities while the light, high positions have low densities. Field F has a somewhat similar pattern on scans two and three, but is completely different on scan 1 due to bare patches in the field crossed by the scan.

In evaluating the differences in scan patterns obtained due to the various parameters previously listed, comparisons in many cases had to

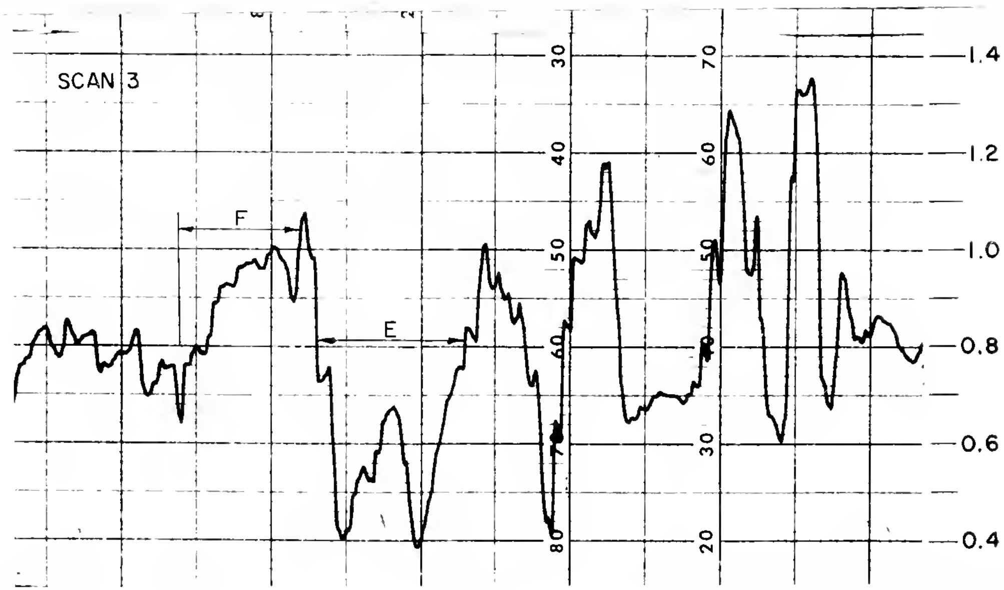


FIGURE 73. LOCATION OF DENSITOMETER SCAN LINES FOR STUDY OF PARAMETER EFFECTS.

REFERENCE POINTS

A EAST BANK (SHADOWS)
B RIVER
C WEST BANK
D HOUSE
E FIELD (PLOWED)
F FIELD (VEGETATED)
G TREE COVERED KNOLL
H FENCE LINE
I SMALL DEPRESSION
J FORESTED SLOPE

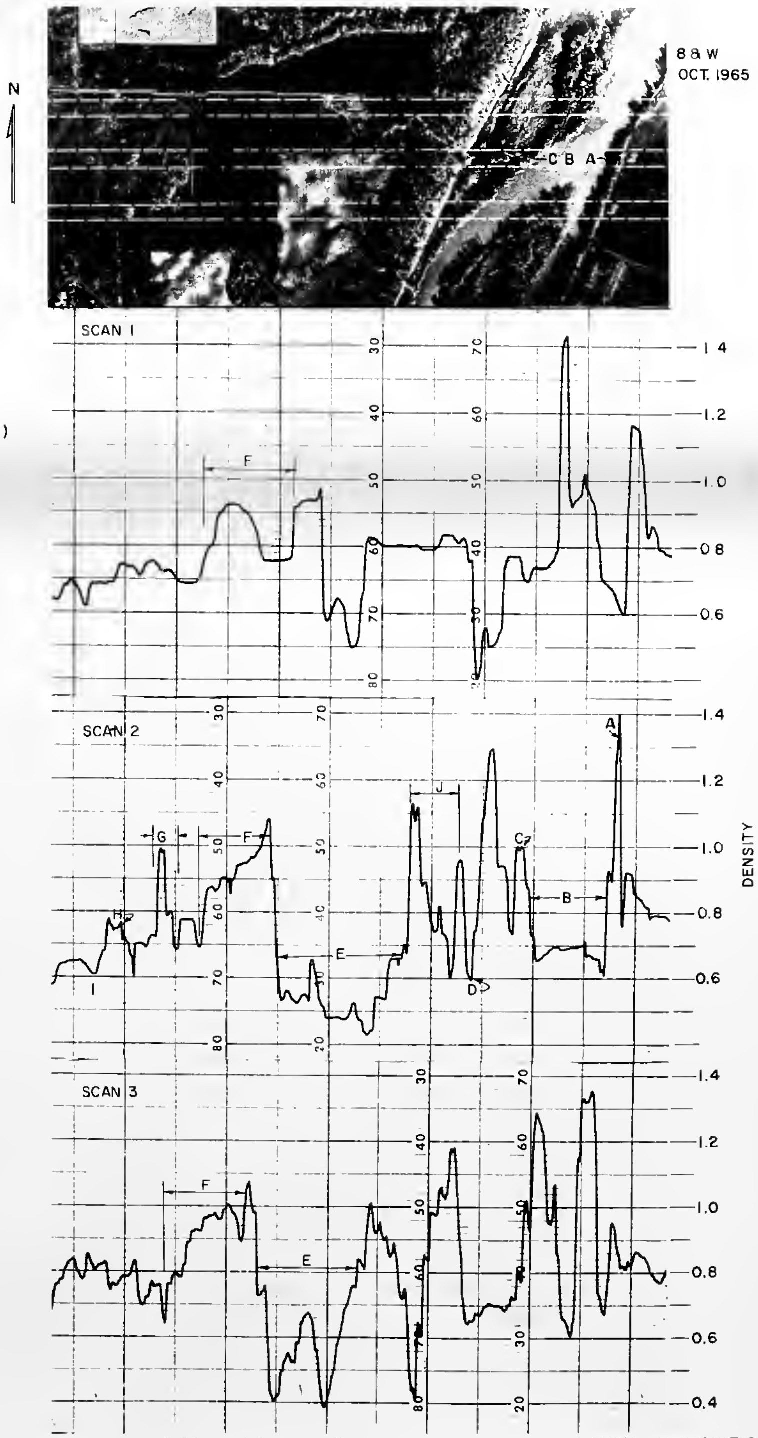


FIGURE 73. LOCATION OF DENSITOMETER SCAN LINES FOR STUDY OF PARAMETER EFFECTS.

be made between scans obtained on the reflection densitometer to scans obtained on the transmission densitometer. Some of the variation in scans is attributed to the aperture size as the reflection densitometer is 4 mm. and the largest opening on the transmission densitometer is 3 mm. However, variations due to the effects of the parameters evaluated could be determined above this initial difference. All parameters except the effect of scale were evaluated in this test strip. The effect of scale was evaluated at Site II because three different scales of photography were available for that site.

Variations Due to Film Types and Scanning Filters

The variations in the densitometer scans obtained on various film types and for various filters on C-P/C-N film are shown in Figure 74. The variations due to the various film types are shown in Figure 74a and were all scanned with the visual filter (no. 106W). These aerial photographs were obtained during the May 2-6, 1966 flight program. Several of the reference zones located in Figure 73 are shown in this figure.

The variations in the scan obtained varies with the type of film and demonstrates the tonal values for many of the features noted in Chapter 5 in comparing the various film types. In evaluating the scans, high densities indicate dark tones, while low densities indicate light tones. On film types B-I and C-I, the river (B) and east bank shadows (A) (see Figure 73) have high densities which is as expected on these film types. On the other types, the shadow (A) has a greater density than the river (B). Comparing fields E and F, (both bare at this time of year), it is seen that very little variation is noted on the B-I. Similar conclusions were noted in the previous chapter for this film type, i.e.,

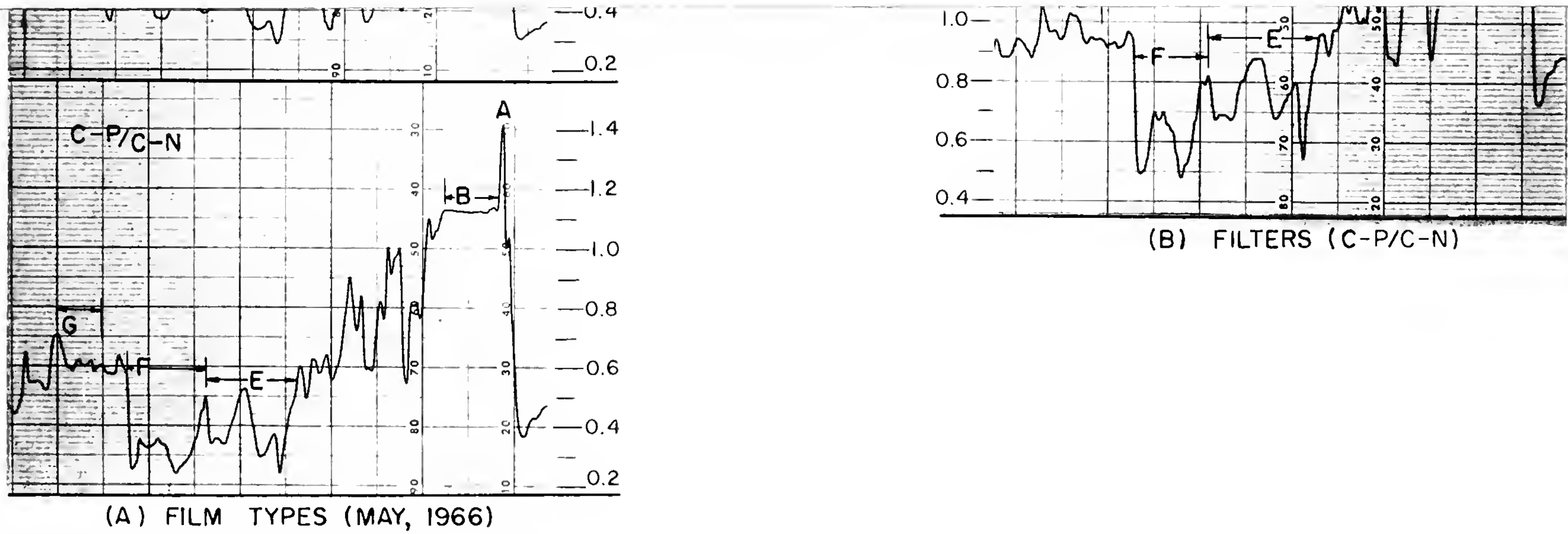
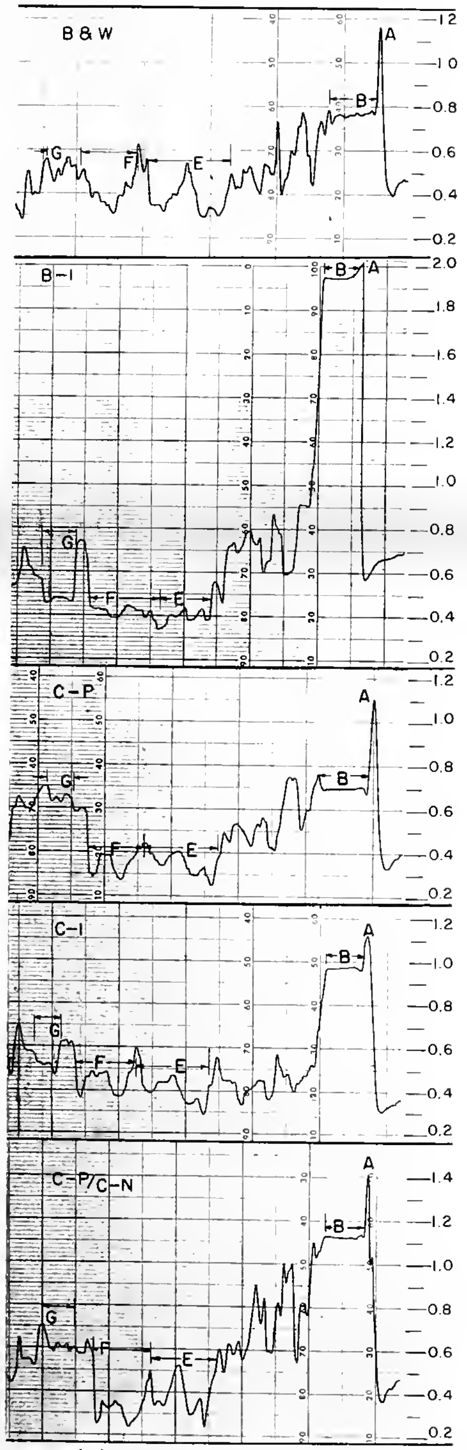


FIGURE 74. VARIATIONS IN DENSITOMER SCANS DUE TO FILM TYPES AND FILTERS.

324



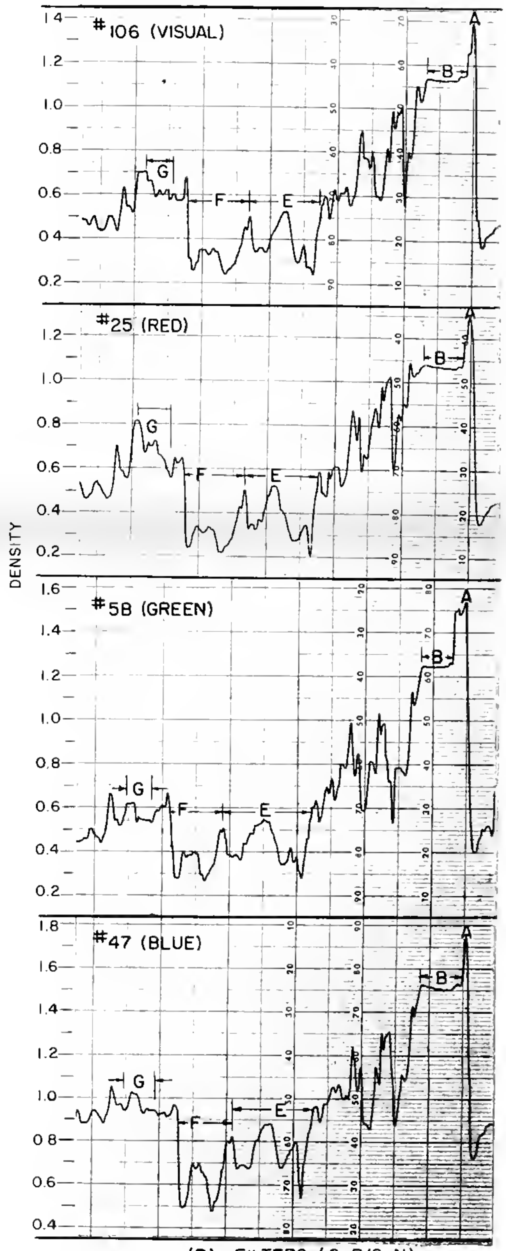


FIGURE 74. VARIATIONS IN DENSITOMER SCANS DUE TO FILM TYPES AND FILTERS.

the contrast between soils are not very great on B-I film types. For the other types, more contrast is noted in these two fields (depicted by greater variations in density). Area G, the tree covered knoll appears light on B-I and C-I (high reflectance of vegetation in photographic infrared region) and in moderate tones on the other film types; it is seen that no two give the same pattern. Therefore, the type of scan obtained in a given area would depend on the type of film used.

Comparing the scans obtained with different filters on the same film type (Figure 74b) it is seen that the overall scan patterns are very similar but some differences are noted. In fields E and F, the smallest contrast between the soil conditions present (depicted by less range in density) is obtained with the green filter. The others are about the same. The blue filter gives overall darker tones as evidenced by the generally higher density of the scan. This feature was observed when using the blue filter in the interpretation phase. The greatest contrast between the bare fields (E and F) and the tree covered knoll (G) is obtained with the red filter. This confirms previous statements that a greater contrast is noted in using the red filter in studying C-P film.

Variations Due to Seasonal Effect

The effect of seasonal variations on the densitometer scans is shown in Figure 75. It is evident from this figure that quite different densitometer scans are obtained for the same area at different times of the year. Since the film type is B-I, tones due to water, shadows and vegetation are distinct. Actually several different factors influence scan results. These are differences due to crops in summer and fall relative to spring (fields E and F); differences due to sun angle as demonstrated

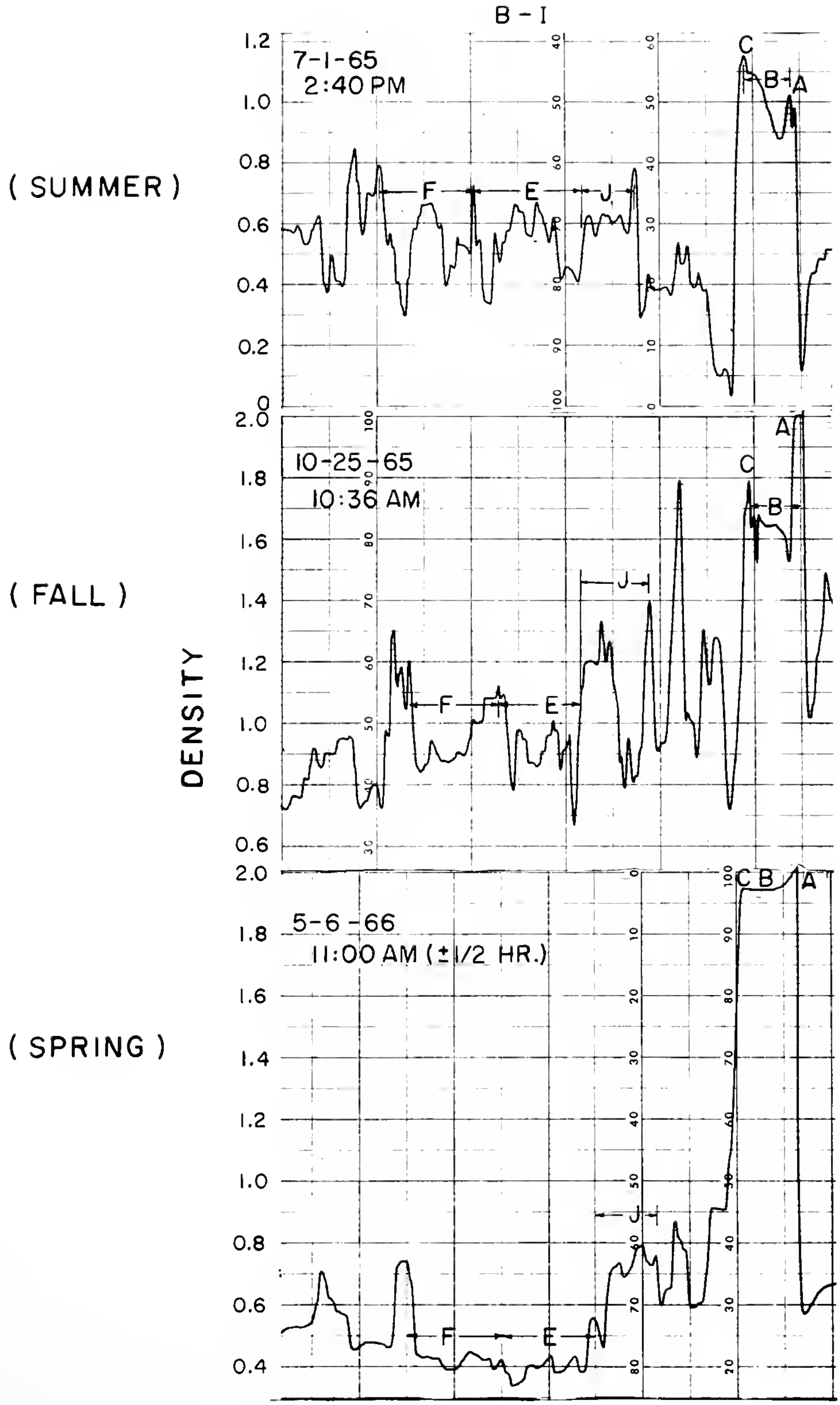


FIGURE 75. VARIATIONS IN DENSITOMETER SCANS DUE TO SEASONAL EFFECTS.

by shadow effects(area J); and differences due to time of day also as demonstrated by shadow effects (areas A and C). In comparing fields E and F during the three dates significantly different patterns are seen in the fields due to vegetation cover. Actually on none of these dates are the fields completely covered with vegetation, but the slight changes cause difference in tonal patterns and therefore in densitometer scans. In the spring flight, the soils are completely bare; therefore, the low tonal contrast. In early summer and in fall some vegetation cover is present to cause significant tonal contrasts.

The effect of the sun angle is best demonstrated by area J which is a tree covered area (refer to photograph in Figure 73). In spring and summer, the sun angle is high and shadows are short; therefore, contribute little to tonal pattern. In the fall however, when sun angle is low, the shadows are long and a significant tonal change occurs. This is evident in the extreme tonal changes in area J in the fall scan.

The effect of time of day is indicated by points A and C. In the morning when the sun is in the east, the shadows on the east bank are longer; therefore, the shadow area being larger, point A has a greater density (fall and spring flight). In the afternoon when the sun is toward the west, the shadows on the west bank are longer; therefore, point C has a greater density. Another example of the low sun angle is demonstrated in the fall scan. Even though the photograph was taken in the morning, the east bank having the longer shadow, the low sun angle produces significant shadows on the west bank also and a high density is also obtained.

Variations Due to Aperture Size

The effect of aperture size on densitometer scan patterns is demonstrated in Figure 76. These scans were measured on a B-I negative. The scans with circular aperture sizes of 3mm, 2mm and 1mm (Figure 76a) were obtained on the transmission densitometer (TD-102) at an approximate scanning rate of 0.1 inches/second, or one inch on the scan is equivalent to one inch on the photograph. The scans with circular effective aperture[1] sizes of 0.2mm, 0.02mm and 0.001886mm (Figure 76b) were obtained on a microdensitometer at a scanning rate of 4mm/minute, or 1 inch on the scan is equivalent to approximately 0.08 inch on the photograph. These microdensitometer scans were performed by the U.S. Army, Cold Regions Research Engineering Laboratory. Because of this slow recording speed and correspondingly large horizontal scale, only a portion of fields E and F scan lines are included in Figure 76b. The portion included is indicated by the dashed vertical lines on the scans in Figure 76a. As noted by the sequence of fields E and F, the scans on the microdensitometer (E to F) are 180 degrees opposite to those (F to E) on the transmission densitometer. The break between the fields is shown by a dash-dot line.

In analyzing these scans on the B-I negative, it must be realized that the density-tonal relationships are reverse to the previous examples of positive prints. On the negative, the light tonal patterns present on the photograph are recorded in higher densities and the darker patterns in lower densities. This is demonstrated by the relationships of areas A and B. This is opposite to the patterns noted in the previous figures.

Comparisons of the scans in Figure 76 demonstrate that the number of

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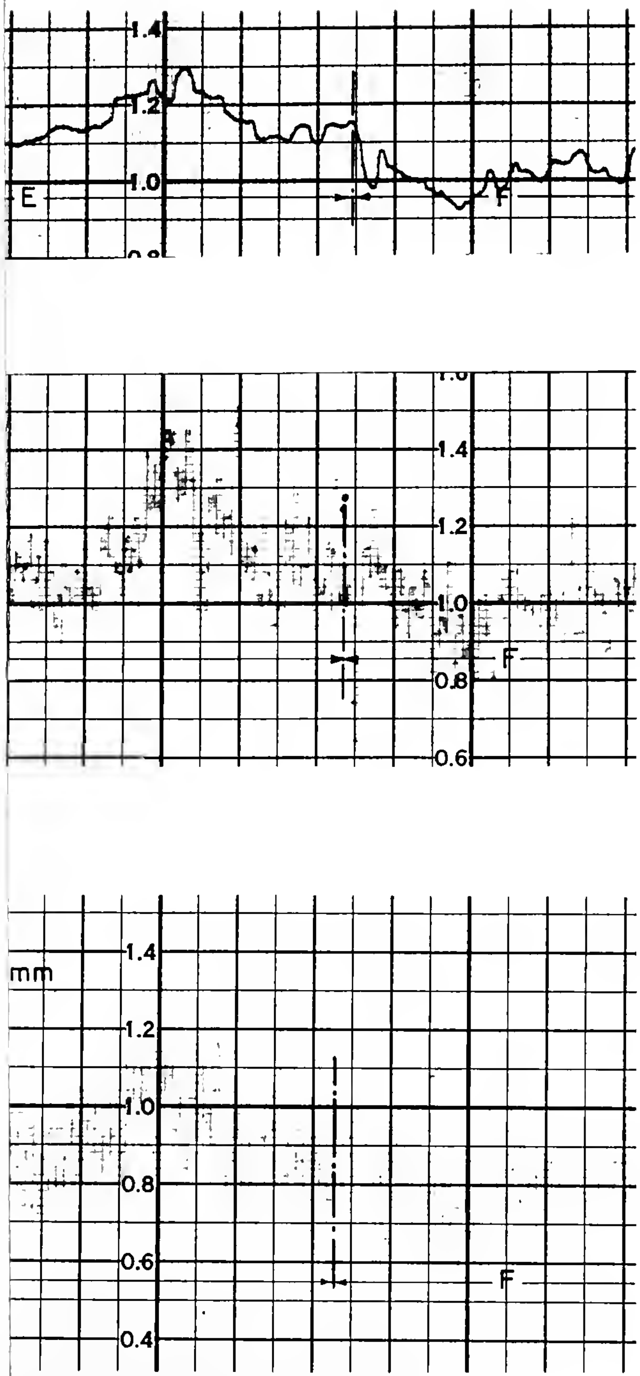
[1] Effective aperture = $\frac{\text{actual aperture}}{\text{system magnification}}$



CANS ON MICRODENSITOMETER

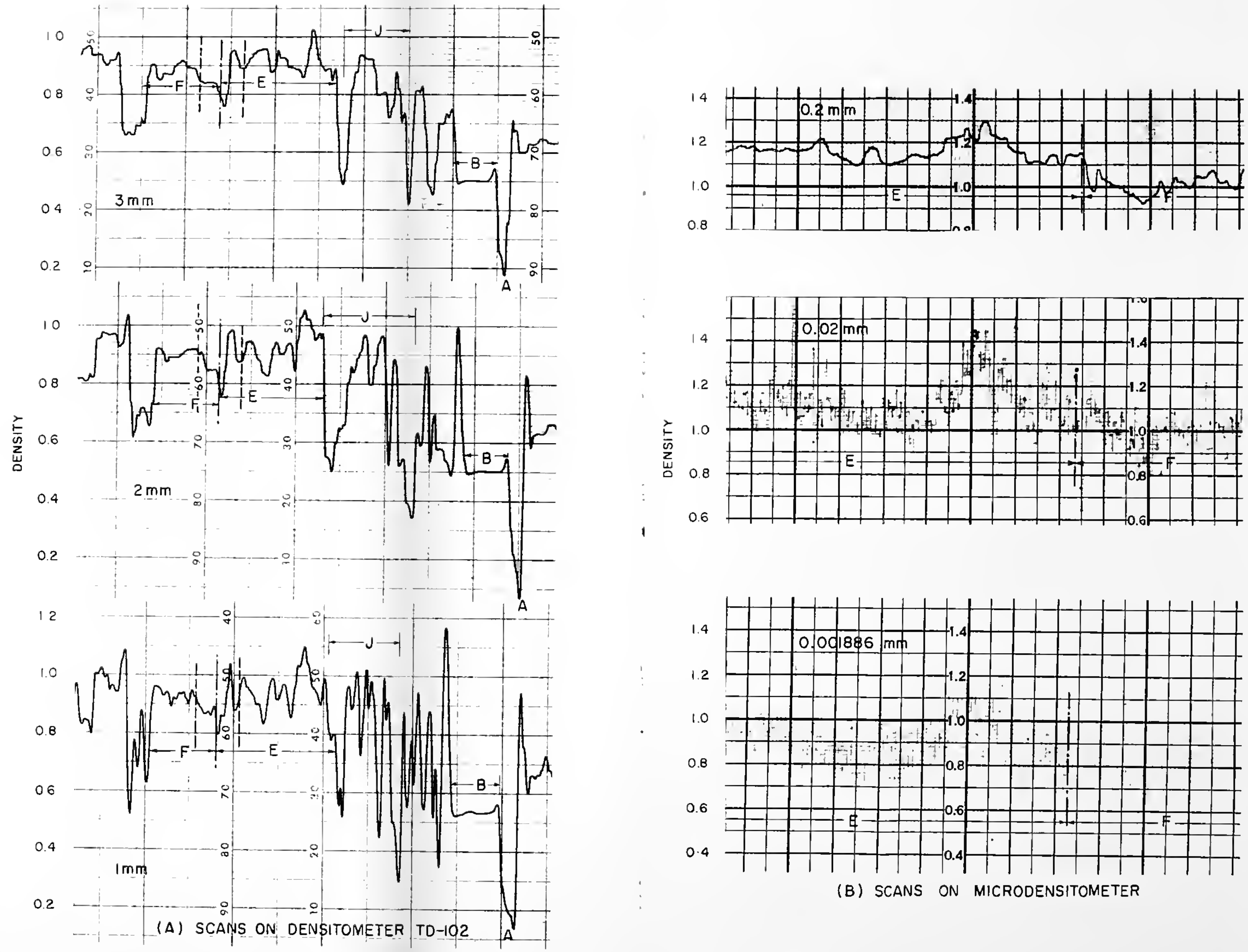


FIGURE 76. VARIATIONS IN DENSITOMETER SCAN DUE TO APERTURE SIZE.

significant changes in density obtained on a densitometer scan is inversely proportional to the aperture size. With large size apertures, more area is exposed to the scanning spot at one time; consequently, an average of the light and dark tones covered by the scanning spot are recorded. As the aperture size is decreased, finer and finer tonal patterns are measured and more detail recorded. If the aperture size is reduced still further, a point is reached where the scans are recording the granularity of the film and the information desired is lost in the detail. These features are observed when comparing the patterns for fields E and F on the six scans and also the patterns for area J, the tree covered slope, on the three densitometer scans. Taking J first, it is noted that as the aperture size decreases, the amount of detail and degree of contrast observed increases. In the first scan, the spot is averaging the tones due to the individual trees and their shadows, while in the latter one, they are individually scanned. In comparing the six scans for fields E and F, it is also apparent that the amount of detail and degree of contrast obtained increases as the aperture size decreases. For example, the range of density shown in the designated band on the 3mm scan is about 0.2 density units, while on the 0.001886mm scan it is about 0.8 density units. The scan patterns for the smallest two aperture sizes indicate that possibly the effects of film granularity are being measured.

Variations Due to Scale of Photography

The effect of scale of photography is similar to that of aperture size, to a point. Instead of varying the size of the aperture in studying a photograph at a given scale, the aperture was maintained constant and different scale photographs were scanned. To obtain the same final

scale of the scan pattern, the speed of the recorder and the rate of scanning were adjusted for each photograph. The difference in the amount of detail obtained and the contrast between areas are clearly evident in Figure 77.

The scans indicated in Figure 77 were performed on B&W photographic prints at the scales shown, with the reflection densitometer. As the scale is increased, a greater amount of detail can be noted on the photograph and therefore the greater the detail of the scan obtained. The differences in the amount of detail and contrast obtained are evident in Figure 77 (refer to areas, K and L). Point K represents a plowed field (point 11 on Figure 52, Chapter 5) and point L represents a gravel pit area (point 10 on Figure 52, Chapter 5). The overall pattern appears similar for these areas, but as scale is increased, the amount of detail obtained also increases.

Summary

The previous examples have demonstrated that the densitometer scans obtained from aerial photography are influenced by numerous parameters including the following:

1. Effect of tonal factors, i.e., vegetation, culture, moisture condition, intrinsic soil color and type of soil;
2. Type of film;
3. Type of filter;
4. Season of photography;
5. Aperture size; and
6. Scale of photography.

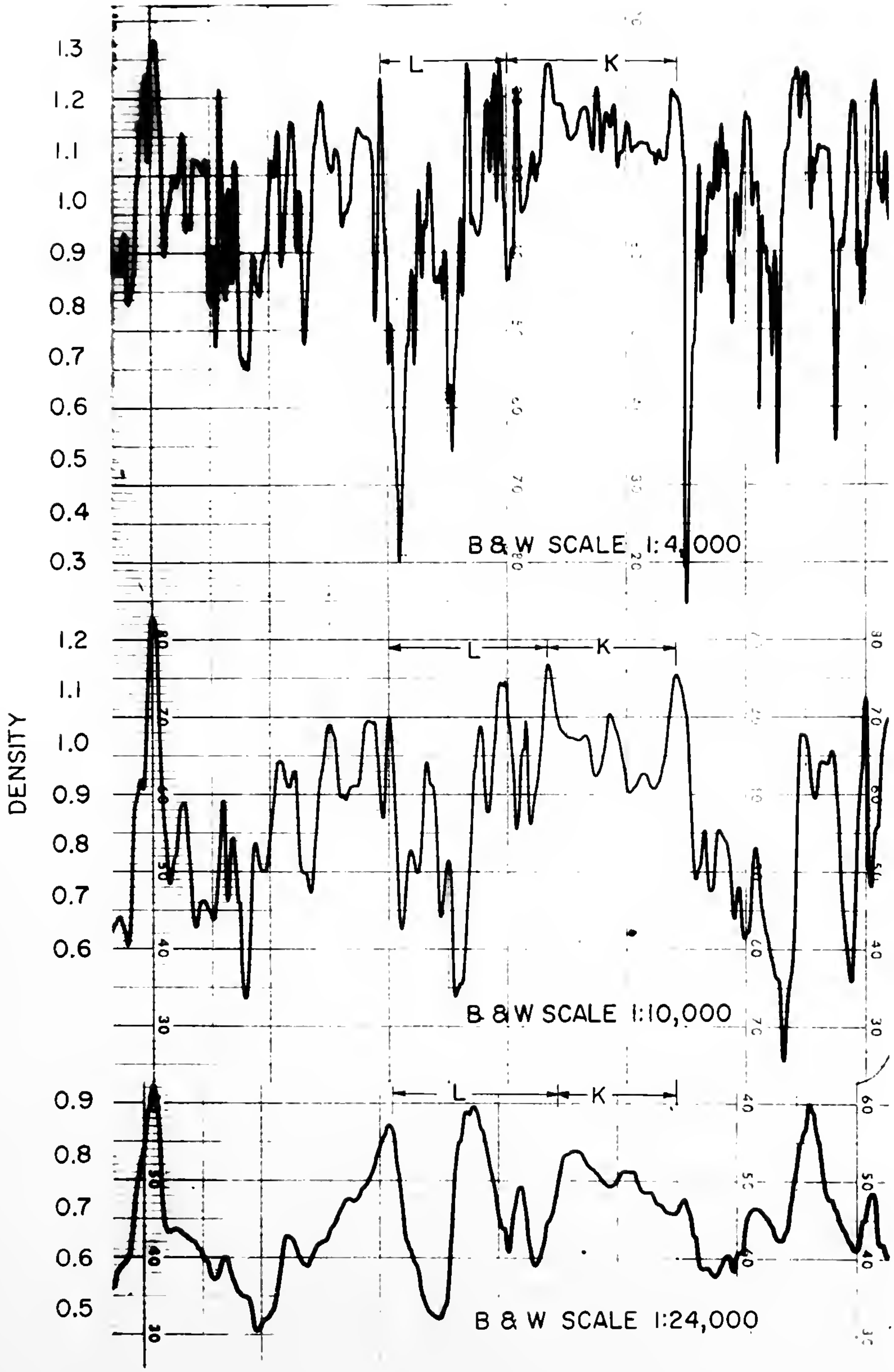


FIGURE 77. VARIATIONS IN DENSITOMETER SCANS DUE TO SCALE OF PHOTOGRAPHY.

These are not all the parameters that affect the scan. Numerous others such as exposure, processing, printing of the film will also affect the scan pattern. These and many others have been discussed in Chapter 3.

These features demonstrate that in order for an automatic interpretation system to be successful for identifying the various land forms and soil conditions, some technique has to be developed to take into account these various parameters. Unlike the qualitative interpretation procedures where the interpreter adjusts for many of these parameters by studying only relative tones, this is not possible in quantitative systems. No technique has been developed as yet which can describe to a machine how to make the decisions the human interpreter makes.

Isotonal Mapping Studies

The preparation of isotonal maps, or maps produced by connecting points of equal film density (55) was attempted to determine whether areas of similar soil conditions could be delineated based on differences in density on the film. This attempt was unsuccessful for all the reasons indicated in the previous section plus two additional reasons. First, because of the inaccuracies in the scanning technique, exact locations of points were difficult. Second, the reduction of data from the scans were tedious and very time consuming. The maps produced by this method did not resemble the tonal patterns present on the original photographs. Another technique attempted was that of taking point measurements on a half-inch grid and plotting the isotonal lines from this data. This method also, did not include all the tonal variations present on the original photograph.

Measurements on Color Photography

Introduction

A problem facing the interpreter using color photographs is a method of describing the various colors present on the photography which aid in the interpretation. The use of common color names is unsatisfactory unless the sample of the exact color is also available to the reader. Chapanis (19) has demonstrated that there is variability among various observers as to what they consider the common colors to look like. An additional factor to be considered is that for any automatic interpretation system, using color photography, a method is needed to reduce information on the various colors present into data that can be handled by a computer.

To accomplish these two purposes, investigations were made into the various methods existing for determining and describing colors. For reasons to be discussed subsequently, these methods were not completely satisfactory for project needs. Accordingly, a rapid, simple and reasonably accurate method was developed in this research project which enables any color on the photograph to be described according to a common well known color system (Munsell system) and also provides data that a computer can utilize for an automatic interpretation system. Prior to a description of this method, a brief discussion is necessary on color and color measurements to show what systems are available and how the technique developed fits into the overall color measurement field with respect to accuracy and usefulness.

Color Measurements

Aspects of Color. Color is not amenable to a simple definition as it depends on what phase of color is being described, i.e., physical, psychophysical or psychological (103). These various types and their characteristics or attributes used to describe each type are listed in table 10.

Table 10. Phases of Color (103)

Physics	Psychophysics	Psychology
radiant energy (characteristics)	luminous energy (characteristics)	color sensation (attributes)
1. Radiance	1. Luminance	1. Brightness
2. Relative spectral composition	2. Dominant wavelength	2. Hue
3. Radiant purity	3. Purity	3. Saturation

The definition of color in each phase is different. In physics, color is an aspect of radiant energy; in psychophysics, color is a response of the human retina to physical stimuli; while in psychology, color is a visual sensation which exists only as a temporary consciousness in the mind (103). All three aspects of color are found in the field of colorimetry.

Color Measurement Systems. The two most common methods of color designation in use are the Munsell system (71)(128) and the CIE chromaticity method[2] (29)(71). The Munsell system is a psychological system utilizing a color matching technique where the observer matches the color sample to standard prepared color chips. It is based on a three-

[2] CIE - initials for Commission Internationale de l'Eclairage.

dimensional concept of the color solid (see Figure 78) with the variables hue, value and chroma corresponding to the psychological attributes hue, brightness and saturation respectively. The circumference (hue) is divided into 40 segments with each segment representing a 2.5 Munsell step. The radius (chroma) is divided into twenty or less bands, the exact amount varying in each segment of hue. The vertical axis is divided into ten steps of value.

There are about 1,000 matte finish color chips and about 1450 glossy finish color chips available in this system. A typical example of the Munsell notation which is obtained from matching to these standard chips is 7.5YR 7/6 which corresponds to Hue-Value/Chroma. Further descriptions of this system are found in the Munsell Book of Color (128) and the book by Judd (71).

The CIE chromaticity method is a psychophysical system which defines the color based on the characteristics of luminance, dominant wavelength and purity. Luminance refers to the brightness level, dominant wavelength is the wavelength of the part of the spectrum required to be mixed with achromatic or "white" light to produce the color, and purity is the proportion of the spectrally pure component in this mixture to the sum of the spectrum and achromatic components (29)(71). These characteristics are determined by plotting the tristimulus points (x, y and Y), determined from spectrophotometric measurements and calculations by standard methods, on the chromaticity diagram (refer to Figure 79). The Y term is the luminance value. An example of the determination of the dominant wavelength and purity is demonstrated in Figure 79. Further details on this system are found in references (29) and (71).

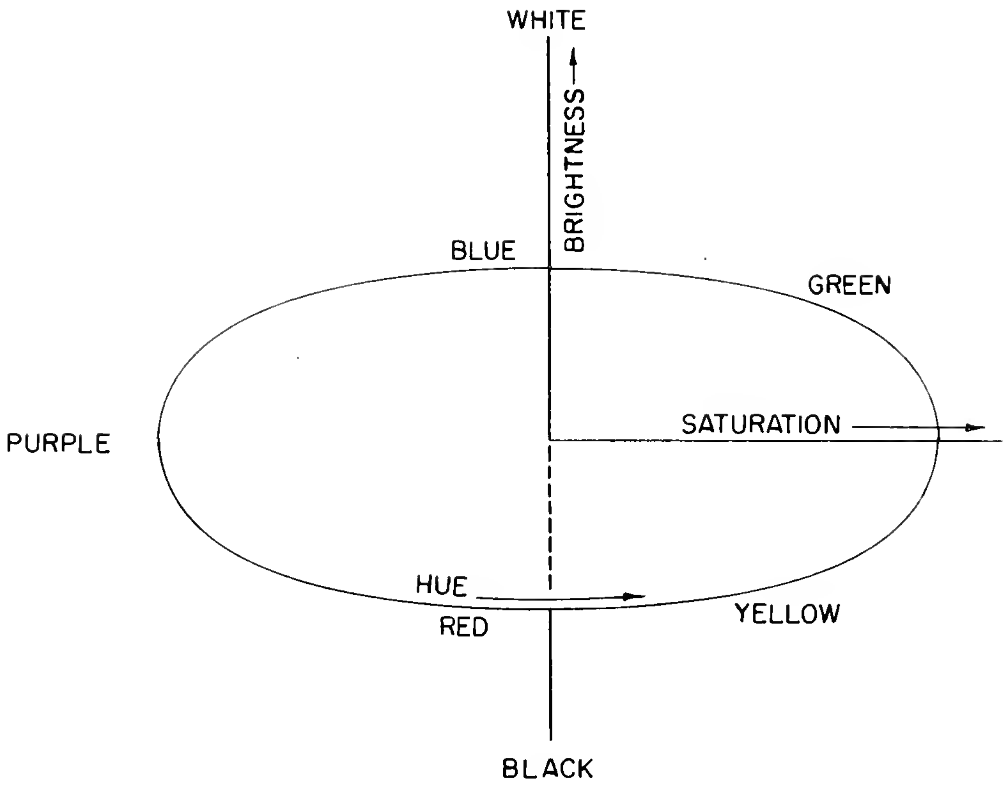
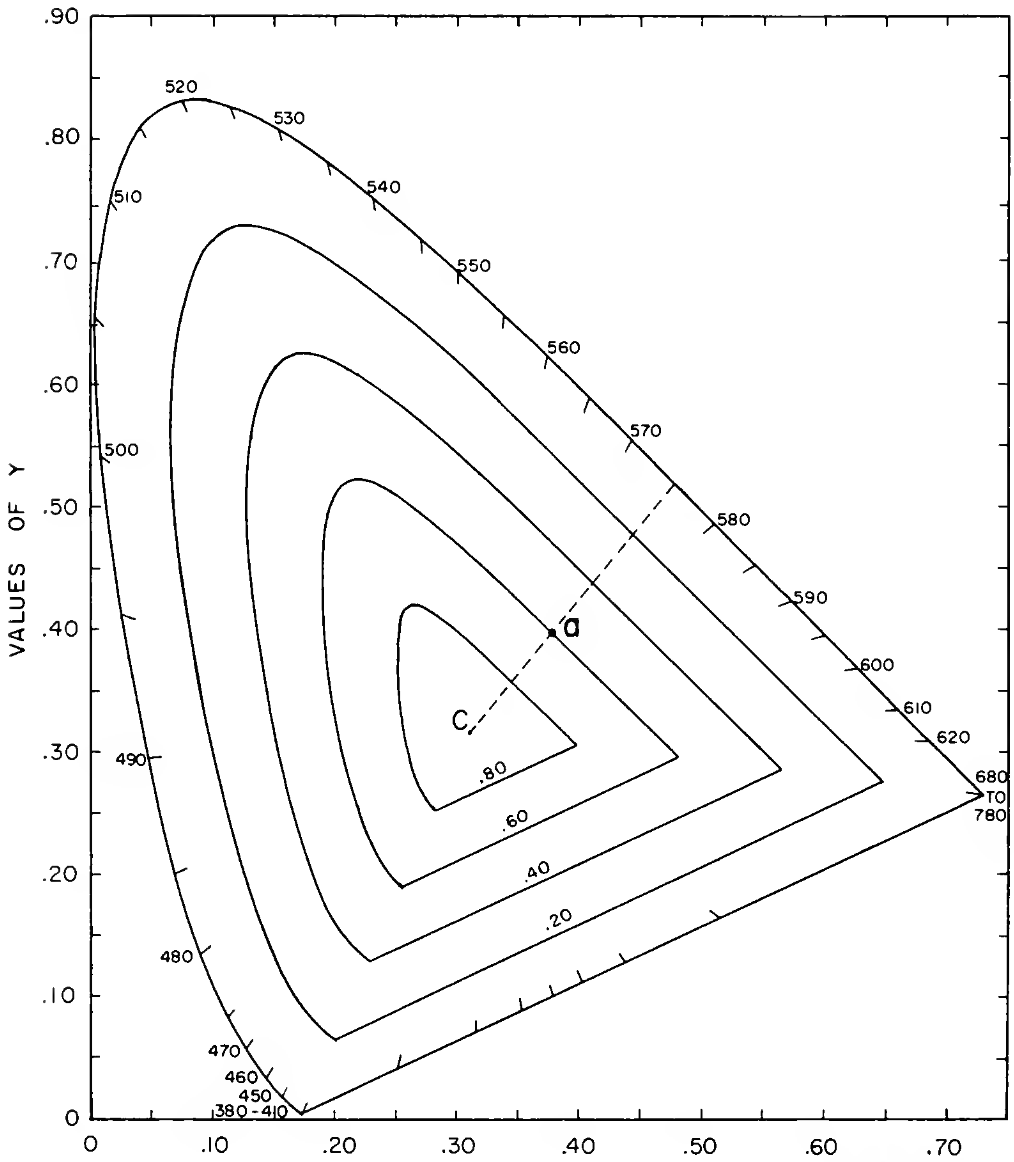


FIGURE 78. PSYCHOLOGICAL DIMENSIONS OF THE COLOR SOLID.



After COMMITTEE ON COLORIMETRY, OSA (29)

EXAMPLE: FOR POINT a WHOSE COORDINATES ARE (.375, .397) THE DOMINANT WAVE LENGTH IS 575 AND THE PURITY 0.60

FIGURE 79. CHROMATICITY DIAGRAM
(SOURCE C — AVERAGE DAYLIGHT)

These are the two major systems utilized to determine the colors of various items. A third purely descriptive system which is commonly used is the system developed by the Inter-Society Color Council and National Bureau of Standards (ISCC-NBS). This system contains 267 descriptive names which are correlated to the Munsell system.

The Munsell system has also been correlated with the CIE chromaticity system. Tristimulus values have been determined for the Munsell chips. Therefore Munsell hue-value/chroma can be determined from CIE chromaticity values (71). The determination of Munsell color names by this system is called Munsell renotations as opposed to Munsell notations when determined directly by color matching. It has been indicated that by interpolation between the Munsell chips or by measurements of colors with spectrophotometers from five to ten million different colors are perceptible (71)(79)(131).

Although both systems described above are standard, well known systems and have been used to measure colors on aerial photographs, they did not meet the needs of this project. These needs include a rapid, simple and reasonably accurate method for describing the colors present on the photography and one which was adaptable to data processing for automatic interpretation possibilities. The use of the Munsell color chips and color matching to the color tones on the photography, at first appearance seemed to have great potential. It was rapid, simple, inexpensive and reasonably accurate. It also had the advantage that anyone having the Munsell Book of Color available could determine the color described by referring to the proper color chip in the book. The main drawbacks to this system were that (1) it was not amenable to automation

as a person had to do the color matching, and (2) the illumination conditions normally encountered for viewing color transpariencies would drastically affect the accuracy of color matching techniques. It has been mentioned in several reports that the condition of illumination is critical in color matching and that the color of an object varies depending upon the amount and spectral composition of the illumination and upon the other colors which are in the visual field at the same time (29)(70)(103).

The limitations in the use of the CIE system include: (1) the equipment needed for measurements are expensive; (2) the determination of the chromaticity values or Munsell renotation is not a rapid process; and (3) there is no reference color system that one could refer to in order to determine the appearance of the color unless the chromaticity value is converted to another color system (e.g., Munsell).

System Developed

The system developed is based on the Munsell chips but involves measurements with densitometers instead of color matching techniques. This method is thus psychophysical, similar to the CIE system. The exceptions are that instead of measuring the complete spectral curve and evaluating thirty or more spectral reflectance points to calculate chromaticity values, only four spectral reflectance (or transmission) points are measured. Also, the equipment used is not accurate, but it is simpler to operate, results are obtained more quickly, and the equipment is less expensive.

Technique. Reflection densitometer readings were taken for every chip within the Munsell Book of Color (matte finish). Each piece

of data consisted of a set of readings taken through four filters (visual, red, green, blue). These readings supplied the basic data which, upon manipulation, gave rise to the system which was developed. After visual inspection and trial and error techniques, basic concepts were developed for the classification system. Subsequently, six random samples were taken from each page, making 240 random samples in all. These readings were used as basic data for the development of a computer program and later for the refinement of the system. The three variables of the Munsell system, hue, value and chroma are evaluated in this method. The charts developed to obtain these notations are shown in Figures 80 and 81.

The abscissa of Figure 80 refers to the pages in the Munsell Book of Color. Each block represents a 2.5 step in hue. Thus the number of the first page is 2.5, the second page 5.0, ... and the fortieth page is 100. The block corresponding to the page is to the left of the number listed (e.g., page 10 refers to the block from the third subdivision to the fourth subdivision marked 10). The corresponding hues for each page are shown at bottom of the chart.

Figure 81 contains the graphs for the solution of value and chroma. Value is obtained first and is obtained from the curve plotted for the empirical relationship $V = 15 - 2.5 \sqrt[3]{\text{visual density reading}}$. Chroma is dependent on value; therefore, it is obtained after value is determined. Chroma notation is obtained from the diagonal lines shown in the chart.

Use of Graphs. The following example will demonstrate the procedure for using Figures 80 and 81 to determine the Munsell color notations.

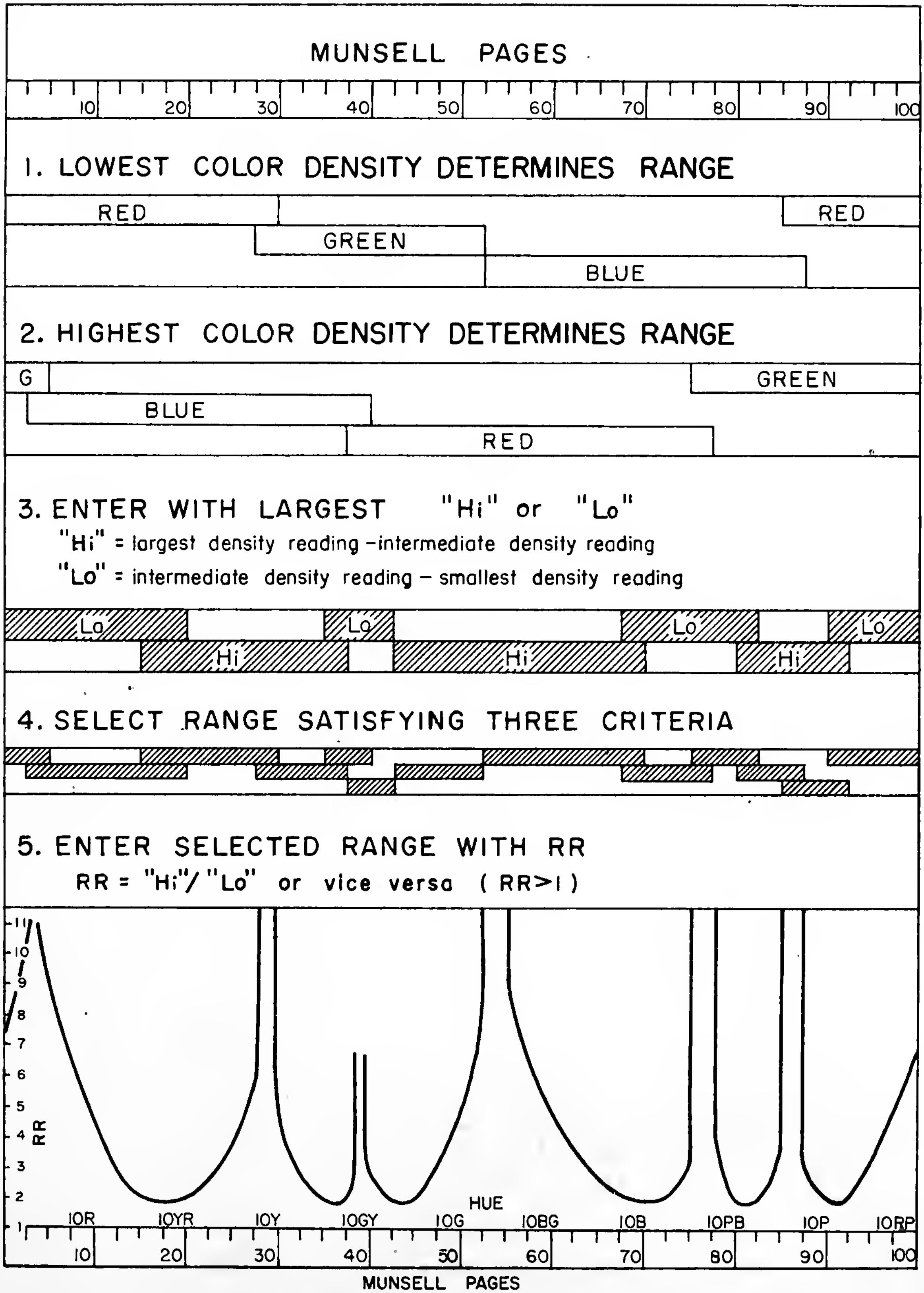


FIGURE 80. TECHNIQUE FOR SELECTION OF HUE.

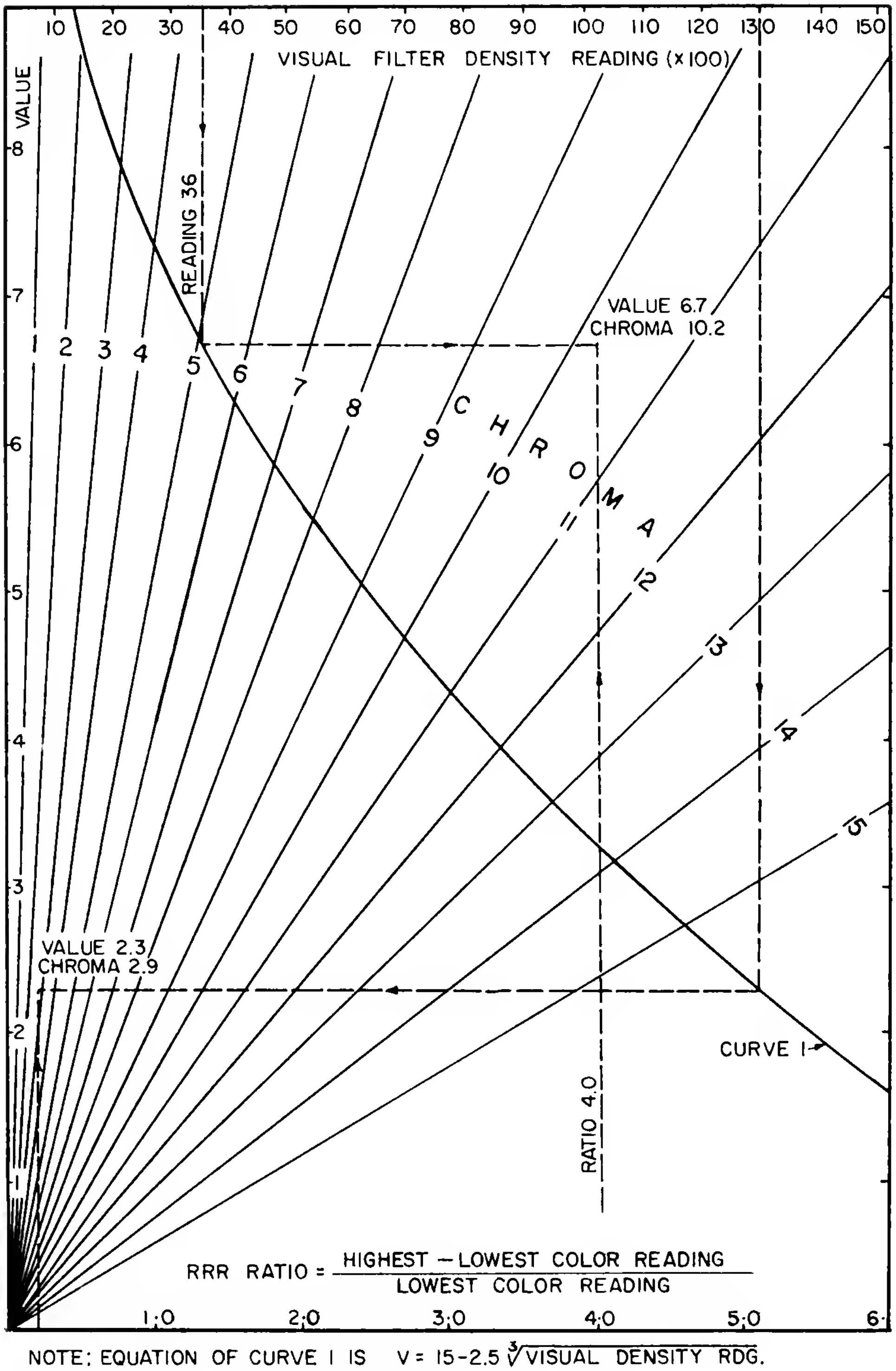


FIGURE 81. TECHNIQUE FOR ASSIGNING VALUE AND CHROMA

Density Readings: Red 0.20 x 100 = 20

Green 0.40 x 100 = 40

Blue 1.00 x 100 = 100

Visual 0.36 x 100 = 36

Calculation of Hue: (Refer to Figure 80)

Only red, green and blue density readings are used in the calculation of Hue.

Step 1. Lowest color density is red, therefore enter red range. This gives Munsell pages 87.5 to 100, and 0 to 30 (0 and 100 correspond).

Step 2. Highest color density is blue, therefore enter blue range. This gives Munsell pages 5.0 to 40. Overlap zone from steps 1 and 2 are 5.0 to 30.

Step 3. "Hi" is 100 - 40 = 60.

"Lo" is 40 - 20 = 20.

Therefore "Hi" range, being largest, is used. Select the "Hi" range which corresponds to the overlap zone of steps 1 and 2; i.e., 17.5 to 40. Overlap zone from steps 1, 2, and 3 is now narrowed down to 17.5 to 30.

Step 4. Range satisfying above three steps is shown in this step. (17.5 to 30).

Step 5. RR = "HI"/"LO" = 60/20 = 3

Enter graph with RR = 3. Draw a horizontal line into zone 17.5 to 30. Where line intersects graph within this zone, draw a vertical line to Munsell pages. Solution is page <u>25</u>. This is equivalent to a hue of <u>5.0Y</u>.

Calculation of Value and Chroma: Refer to Figure 81.

Value: Enter top of chart with visual reading of 36 and draw a vertical line until it intersects curve. Value is <u>6.7</u>.

Chroma: Calculate RRR (use color density readings only)

$$RRR = \frac{100 - 20}{20} = 4.0$$

Enter bottom of chart with RRR ratio. Draw a vertical line to intersect a horizontal line drawn from Value determined in last step. Intersection gives Chroma which is read from diagonal lines originating at origin. Chroma = 10.2.

The Munsell notation (to nearest chip in Munsell Book of Color) is 5.0Y 7/10.

Discussion of Graphs. In the graphs for hue it is noted that the last graph contains regions which are unbounded. This is to accommodate large values of RR which occur when two of the colors have the same density reading or nearly so. In the special cases where RR is less than 2 and the horizontal projection of the value does not intersect the graph, a two step band, located at the center of the trough within the remaining zone is chosen.

An additional item noted is that the widths in the principal zones are unequal and these result in unequal subdivisions in further steps. This system was based on the filters present in the reflection densitometer. The unequal width of the principal zones could no doubt be eliminated by careful selection of the red, green and blue filters.

A special technique was developed to evaluate the neutral Munsell chips (white to black). When the three color filter density readings are all within three points of each other (e.g., red-.40, green-.38, blue-.41) the color is taken as neutral (chroma = 0). The value is obtained in the normal manner from the visual density reading.

Prediction Performance. To check the accuracy of prediction of Munsell notations by this system checks were made between the Munsell notation developed by this method and the actual Munsell notations. Three different sets of data were compared. These included: (1) the original 240 matte samples on which the system was developed; (2) 250 glossy samples in the ISCC-NBS Centroid Color Charts (81); and (3) readings taken on additional chips from a second Munsell Book of Color. Accuracies obtained were:

Hue - 85 to 95 per cent within ± 1 Munsell step (one page of book)

99 per cent within ± 2 Munsell steps

Value - 99 + per cent within ± 1 value step

Chroma - 98 per cent within ± 1 unit of chroma (chroma goes in steps of 2, e.g., 2, 4, 6, 8).

The average error in a three-dimensional sense, assuming units of hue, value and chroma are equivalent, was 1.4 units. This would indicate that in the attempt to pick the exact chip, two of the three components would be one unit away, and the third one would be correct.

Comparison of Accuracies. Comparison of the accuracy of this rather simple system to results reported in the literature for the more sophisticated systems indicates the accuracy of this method is not significantly different than these systems. Godlove and Munsell (50) reported that the disagreement between direct color matching method and indirect methods (spectrophotometry and transformation by computation to hue and chroma) indicated the determination by the indirect method was about equal to the uncertainty of the direct method which had an average uncertainty of one Munsell hue step and one-half Munsell chroma step.

Nickerson et al., (130) indicated that the average difference between renotations based on visual observations and renotations based on spectrophotometric methods for some 76 samples was hue 1.2 ± 1.0; value 0.2 ± 0.3 and chroma 0.6 ± 0.2.

These results indicate that at least for determining Munsell notation, the system developed had about the same degree of accuracy as other indirect measuring methods. This method however, had the added advantage that it was simpler, faster and the equipment was less expensive.

Application to Measurements on Color Photography

The system developed was based on measurements with the reflection densitometer on positive matte or glossy surfaces. However, most of the color photography obtained were transparencies, and density measurements could only be made with the transmission densitometer. To check if the system was equally applicable to measurements with a transmission densitometer on transparencies, selected spots were measured on both transparencies and positive color prints made from the transparencies. Care was taken to select areas that had uniform color tones and that the same point was read on both types.

Results of this comparison indicated that transmission readings taken on transparencies can be used to predict a color notation for an object as it would appear on a print. The very light or very dark range of value and chroma does not perform as well for hue prediction (more marked on C-I than C-P). Value and chroma can be predicted fairly well. Value notation corrections to be applied to transparency results are dependent directly on value.

Transmission readings obtained on transparencies to give Munsell notations applicable to prints are as follows:

C-I

transparency		Conversion to print
hue	-	use directly
value	-	multiply value by two
chroma	-	use directly

C-P

hue	-	use directly
value	-	multiply by 1.5
chroma	-	multiply by 1.5 then subtract 5; when transmission chroma ≤ 3, chroma on print is zero.

Comparisons were also made to determine if Munsell notation could be predicted for positive prints based on measurements of color negatives. Several trends were noted, for example on Aero-Negative color, the difference was 20 hue steps (complimentary colors) while for Agfa negative color the difference was about 10 hue steps. These results are inconclusive however, as it does not represent a large sample.

To describe the colors on aerial photography with a descriptive name in addition to the Munsell notation, the ISCC-NBS method of designating colors was utilized (80). This system contains 267 descriptive names. These names are correlative with the Munsell system and are determined from the Munsell notations.

Preparation of Isochromal Maps

Attempts were made to prepare isochromal maps, or maps showing uniform color regions, similar to the isotonal maps prepared for B&W photography. Maps were prepared from point density readings taken with four filters on a one-half inch grid system. An isochromal trace was also prepared along one continuous scan line. The color zones on the map were determined by utilizing the system developed for determining Munsell hue. These trial maps were then visually compared to the original color tones present on the photography. Zones were noted where colors were comparable between the isochromal map and the original photograph. The limitations on this technique were similar to those for the preparation of the isotonal maps; that is, insufficient grid points were measured to delineate the various color patterns present and the lack of accuracy of location of points on the continuous scans. An additional limitation on the use of continuous scans in this method is the lack of accuracy of locating the same point on the four filter scans. This latter item is not a problem since the equipment can be automated to take care of this.

Crude as these tests were, the correlations made indicated that this method does provide a means of automatic extraction of raw color data from aerial photography. However, further development of this technique is necessary. The potentials for this technique appear great for automatically extracting areas of particular colors which may be related to soils or soil conditions.

Summary

A rapid, and simple system was developed for determining Munsell color notations or ISCC-NBS descriptive color names. The technique is based on measuring the sample point with a densitometer. Four readings are taken per sample point using four filters (visual, red, green and blue) and by using the graphs developed, the Munsell notation is determined. The accuracy of the system for the intended purpose is comparable to other more elaborate methods; however, this method is simpler and faster to apply.

This system can be utilized to describe colors on both positive color prints and positive color transparencies. It was noted that corresponding colors could be obtained on both film types. Measurements of color negatives and positives indicated the possibilities of predicting the final color on the positive print from measurements on the color negative. It was also indicated that isochromal maps could be prepared from the color photography utilizing this measuring technique. This technique has great potential for delineating areas of soils or soil conditions based on particular tonal patterns present on the photography.

The principles used are capable of refinement, if the overall control of photography and accuracy of densitometers is warranted. It is considered that for the purpose used, the accuracy of definition was sufficient.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

From the qualitative analysis and evaluation of the various aerial photography and imagery data collected, it is concluded that:

1. The optimum system for performing detailed engineering soils mapping, considering the presently available equipment, is one which simultaneously obtains multichannel imagery and color aerial photography. The multichannel sensor should have a minimum of seven channels simultaneously collecting information at the same scale, resolution and format and in the following bands: (1) ultraviolet; (2) violet-blue; (3) green; (4) yellow-orange; (5) photographic infrared (0.8-1.0μ); (6) middle infrared (3.0-4.1μ); and (7) far infrared (8-14μ). The color photography should be obtained with a photogrammetric mapping camera with a distortion free lens flown to mapping standards and the film should be a natural color positive transparency type. This combination would provide the maximum information on soils and soil conditions with the minimum amount of field control required. This system requires security clearance for access to the classified equipment and data.
2. For the condition where a multichannel sensor is not available, an alternate system which can be used is one which simultaneously

obtains color photography, color infrared photography, and infrared imagery in the 8-14μ band. Detailed soils mapping of equivalent detail and accuracy as the optimum system can be obtained but it requires more field control than the optimum system. This system also requires security clearance.

3. When access to classified equipment or data is not possible, the system providing the maximum information on soils and soil conditions is one which obtains simultaneous coverage with natural color photography and color-infrared photography. For this system, more field explorations are required than for the previous two systems.
4. Multisensor systems not obtained simultaneously can furnish valuable information for detailed soils information if supporting data has been collected at the time of each flight to indicate the changes that had occurred between the various flights.
5. The <u>single</u> film or imagery type which overall, provided the most information on soils and soil conditions is natural color photography (transparencies). More information on tonal factors can be interpreted on this type than any other single type. In addition, color photography (transparencies) was one of the film types which permitted the greatest amount of magnification and also the greatest amount of fine details could be evaluated for a given scale.
6. The use of a Wratten filter in one of the eyeguards of the magnifying stereoscope increased the contrast between various

items on color and color-infrared photography. This made it easier to draw boundaries between different soils.

7. The value of infrared imagery for detailed soils mapping is that it furnishes supplemental information not obtainable by any other means. This information aids in the identification and delineation of various soils and soil conditions. It also provides converging evidence which increases the accuracy of the analysis. The imagery by itself is not a suitable system for evaluating soils information.
8. K-band radar was found to be of little use for identification and interpretation of soils for this project.
9. Black-and-white infrared photography appeared to be very sensitive to low moisture contents. This was noted but not investigated in this project and offers an area of future research.
10. Season of the year that the flight coverage is obtained has a direct effect on the amount of soils detail that can be mapped. Data on this project confirmed previous conclusions that the spring of the year was the best time.
11. The optimum scale of photography for soils mapping is not a function of altitude alone. The film type and magnification capabilities of the stereoscope are additional factors that influence this. Experience in this project with three different scales, indicated that a medium scale photography (1:8,000-1:15,000) was the optimum scale for detailed soils mapping. The choice of the lower or higher scale of the range depends on the other two factors.

12. Spectral responce curves which give some indication of the reflectance and emittance properties of the various soils can be developed from multichannel data by normalizing procedures.

From the quantitative measurements of the aerial photography and imagery collected, it is concluded that:

1. For the test areas investigated, diagnostic density patterns identifying the various land forms could not be developed. There is more variability in the density patterns due to the various parameters investigated than there are due to differences in land forms. This would suggest that the possibility of automatic interpretation by this technique alone is not feasible.
2. The method of color measurement by means of densitometry offers a simple and rapid means of obtaining Munsell notations and descriptive names based on ISCC-NBS system. For the intended purpose, the accuracy of this method is commensurate with results obtained on more elaborate color measurement equipment.
3. The use of isochromal maps offers a greater potential for delineating areas related to soils and soil conditions than corresponding isotonal maps. The basic technique for development of these maps is indicated but more research is needed in their development.
4. From the various techniques investigated, the greatest potential for automatic interpretation appears to be through the use of multichannel data and isochromal maps. Research is needed into techniques for reducing the data and programming it for computers.

From an analysis of the type of information obtained from the field investigations, it is concluded that:

1. Radiometer field measurements are of value in determining the best time for aerial infrared imagery flights when the contrast between soils of interest are maximum. Also, if measurements are taken of representative field sites, they are of value in the interpretation of the imagery obtained.
2. Other ground truth data which are of assistance in interpreting the data include meteorological data, limited ground photographs and information on the calibration settings of imagery scanners.
3. Resistivity surveys can be of great assistance in not only indicating subsurface information, but also in indicating the different types of surface soils present in an area. Limited soil profiles by standard borings are needed with this method to obtain maximum usefulness.

Recommendations

This project was the first phase of a project to develop the technique for preparing "Annotated Aerial Photographs as Master Soil Plans." Based on the results obtained in the first phase the following aerial system is recommended for the second phase.

1. A multisensor approach should be utilized to obtain the basic information on soils and rock conditions. The optimum system previously described is suggested, supplemented by black-and-white photography for use in preparing the detailed map by photogrammetric mapping techniques. If the optimum system is not available, one of the suggested alternate systems should be used.

2. The area chosen for mapping should have a greater variety of soil and rock conditions present than the test areas for this project. This would be a check of the system for land forms and soil conditions, not previously studies.
3. Field radiometer readings should be taken prior to flights obtaining infrared imagery to determine trends in the area and to determine when the optimum time for flights should be. It is also suggested that they be taken during flights for ground truth information.
4. Several passes with the imaging sensor should be made decreasing the range of the setting of the instrument in each pass. The last pass should bracket the major soils with a very small temperature range in order to obtain the maximum contrast. This range should be previously determined by field radiometer studies.
5. Although K-band radar was of little value for evaluating soils, it may be of some value in rock areas. A limited flight might be planned for the area if rock exposures are to be expected.
6. The flight for final mapping purposes should be made in the spring of the year before the leaves develop.

Recommendations for further study include:

1. Techniques should be developed to further refine the data obtained from multichannel imagery for processing by computers. A greater number of different soils and rock units should be investigated by this method to determine if they can be differentiated by comparisons of their spectral response on the various channels.

2. The technique for developing isochromal maps should be investigated further. Maps should be prepared in areas where soils are extensively exposed to determine if this color mapping system is sensitive enough to differentiate different soil types and soil conditions.

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APPENDIX A

APPENDIX A

DATA COLLECTION AND EXISTING INFORMATION

Appendix A contains the data collected as part of the field investigations including resistivity surveys, soil moisture contents and meteorological data. Existing borings and well log information are also included.

The location of the various sampling points, borings, and well logs are shown in Figures A.2 and A.3. Figure A.1 shows the location of the additional resistivity survey points which are not shown in Chapter 4.

a

100							
40			45			50	
39			88			103	
	40	38		42	45		51
30			77			77	
	35	36		35	35		34
59			70			68	
	32	31		33	29		32
74			76			81	
	33	34		35	36		37
16			198			188	
	98	97		91	92		89
63			61			64	
	18	34		18	35		21

90			95			100	
89			87			79	
	45	29		45	28		43
62			59			57	
	31	24		29	24		28
79			76			72	
	40	30		40	28		38
73			72			68	
	32	32		32	30		29
39			130			124	
	62	63		59	59		55

40			145			150	
72			70			68	
	40	22		39	22		39
50			48			47	
	22	20		21	20		20

r Engineers," Purdue University

eft and right

Table A.1 . Resistivity Data Collected - Spring 1965[a]

Geographic Location	Station No.	5	10	15	20	25	30	35	40	45	50
Sec.4 T23N, R5W Tippecanoe Co. Ind.	A(E)[b]	50[c]	35	50	56	65	80	85	89	88	103
		20 22	16 14	22 22	25 25	28 28	35 35	35 38	38 40	38 42	45 51
	B(E)	55	54	72	76	79	81	81	80	77	77
		22 28	22 25	31 35	35 35	37 36	38 36	39 36	37 35	36 35	35 34
	C(N)	36	35	51	51	61	62	66	69	70	68
		13 14	11 14	18 22	22 25	26 28	26 27	29 31	31 32	31 33	29 32
	D(N)	68	30	29	44	56	62	69	74	76	81
		34 28	12 11	12 10	19 17	24 23	28 27	31 30	33 33	34 35	36 37
	E(N)	210	158	196	212	228	225	224	216	198	188
		104 100	78 74	98 91	112 94	119 102	118 100	117 100	112 98	97 91	92 89
	F(E)	122	97	115	103	97	86	73	63	61	64
		67 48	54 34	65 42	56 38	51 37	46 31	40 24	36 18	34 18	35 21

Geographic Location	Station No.	55	60	65	70	75	80	85	90	95	100
	A	105	106	102	92	93	93	90	89	87	79
		45 52	45 53	42 53	36 52	36 51	36 51	33 49	30 45	29 45	28 43
	B	75	74	71	72	69	67	66	62	59	57
		34 35	31 34	30 34	29 35	28 35	27 34	27 33	25 31	24 29	24 28
	C	74	71	73	73	74	77	78	79	76	72
		30 37	32 34	30 35	30 36	30 38	31 40	31 40	31 40	30 40	28 38
	D	84	86	82	80	80	77	73	73	72	68
		37 38	38 39	36 37	37 37	40 38	34 35	33 33	32 32	32 32	30 29
	E	189	181	168	157	154	152	147	139	130	124
		93 90	91 83	85 75	79 70	78 68	78 68	75 64	69 62	63 59	59 55
	F	70	63	64							
		41 23	38 17	38 17							

Geographic Location	Station No.	105	110	115	120	125	130	135	140	145	150
	A	78	73	74	81	74	74	73	72	70	68
		27 43	26 40	25 41	28 43	25 43	24 43	23 41	23 40	22 39	22 39
	B	54	55	55	52	50	51	50	50	48	47
		23 26	23 26	22 25	21 23	21 23	20 23	20 22	20 22	20 21	20 20
	C	72	68	68	67	66					
		27 39	25 38	23 38	24 38	23 36					
	D	67	67	64	62	56	54	52			
		31 29	30 29	29 27	27 27	25 24	24 23	24 21			
	E	111	100	93							
		52 45	50 41	47 40							

a - Data collected as part of field problems for Geology 691 "Geophysical Exploration for Engineers," Purdue University
b - Letter (E) or (N) designates cardinal direction instrument facing.
c - Lee Partion Method used. Upper reading is total resistance and lower readings are left and right resistance readings respectively.

Geographic Location	45	50	55	60
Sec.5 T22N, R6W Warren Co. Ind.				

Table A.2 . Resistivity Data Collected Fall 1965 and Spring 1966

Geographic Location	Station No.	Resistance Readings ohm - cm x 100											
		Depth (Feet)											
		5	10	15	20	25	30	35	40	45	50	55	60
Sec.5													
T22N, R6W	1N[a]	51[b]	41	60	69	80	91	99					
Warren		21 27	17 22	28 30	34 34	39 39	43 44	49 48					
Co. Ind.	1W	39	34	51	63	73	83	90					
		21 17	18 13	28 22	32 27	38 34	41 38	44 42					
	2N	94	50	61	72	85	93	105	112				
		44 47	25 23	31 28	37 33	45 37	49 41	56 45	58 50				
	2W	91	51	67	76	88	98	107					
		44 45	26 23	32 33	37 35	42 41	48 47	52 50					
	3N	70	45	63	77	89	101	112					
		34 34	21 23	29 32	38 36	44 42	51 48	58 51					
	3W	71	44	62	75	85	98	108	115				
		37 32	22 18	30 29	37 35	42 41	50 45	56 49	59 54				
	4N	106	63	82	95	113	125	140	148				
		60 47	31 30	40 40	46 47	56 55	60 62	67 69	72 73				
	4W	118	61	84	92	110	124	137	146				
		61 56	32 27	44 35	46 43	54 53	61 60	66 66	72 76				
	5N	103	54	85	98	123	139	155	162				
		50 49	28 26	43 40	49 49	60 60	70 66	77 72	84 76				
	5W	98	62	80	94	110	124	137	146				
		47 47	31 29	40 38	46 44	53 53	60 60	65 67	70 71				
	6N	130	69	99	116	131	145	156	165				
		70 57	36 31	53 44	58 55	64 65	70 74	75 79	80 82				
	6W	118	68	93	114	130	145	156	171				
		59 57	34 34	45 47	54 57	61 66	68 64	75 80	82 87				
	7N	75	51	78	97	115	129	138	145				
		37 38	24 25	38 39	46 48	55 55	61 63	66 68	70 68				
	7W	69	50	71	92	110	126	139	146				
		31 36	24 24	35 35	43 45	53 54	60 62	68 69	71 72				
	8N	100	59	90	115	121	133	138	145				
		46 52	29 29	42 46	48 54	55 69	62 68	68 72	69 75				
	8W	112	66	90	112	132	144	157	168				
		53 57	30 34	43 45	53 57	62 66	70 72	77 77	83 83				
	9N	88	51	80	98	114	129	137	144				
		45 41	24 25	36 40	45 50	53 57	61 65	66 68	69 71				
	9W	81	47	74	87	102	115	122	129				
		41 37	23 21	36 35	41 42	49 49	54 57	57 59	59 64				
	10N	80	46	69	84	103	112	124	127				
		44 37	24 22	30 34	40 43	49 51	54 56	62 61	61 65				
	10W	78	51	76	87	108	116	124	139				
		35 40	23 25	34 36	40 43	47 54	54 58	57 62	61 65				
	11N	127	67	85	95	107	117	125	133				
		59 64	31 33	38 42	44 48	50 53	55 60	60 62	63 63				
	11W	109	56	72	88	104	116	124	135				
		53 53	29 26	37 32	44 42	51 49	58 56	61 60	67 65				

Geographi Location	5	50	55	60
Sec.5 Warren Co Cont'd				

Table A.2 . (Cont'd.)

Geographic Location	Station No.	Resistance Readings ohm - cm x 100 Depth (Feet) 5	10	15	20	25	30	35	40	45	50	55	60
Sec. Warren Co. Cont'd	12N	101	59	77	91	105	118	148	131				
		48 52	30 28	38 38	42 46	51 52	58 58	73 72	64 62				
	12W	109	55	76	89	104	116	126	130				
		53 52	28 26	39 35	44 44	50 53	54 60	59 63	63 65				
	13N	112	62	79	96	109	125	139	144				
		53 56	29 31	38 40	45 49	53 54	60 62	67 67	71 73				
	13W	104	57	77	93	109	117	130	137				
		50 51	25 31	35 40	44 47	53 54	56 58	62 65	67 68				
	14N	74	51	71	91	105	120	134	143				
		38 35	24 26	34 36	44 45	51 52	59 59	65 66	69 73				
	14W	76	51	75	93	108	120	134	147				
		32 40	21 26	34 37	43 45	51 53	56 60	64 67	69 74				
	15N	75	53	77	93	112	123	140	150				
		40 32	26 25	36 37	45 43	57 52	62 57	71 65	76 71				
	15W	78	58	80	96	113	135	144	154				
		44 33	32 27	41 37	50 45	59 54	69 59	76 66	81 72				
	16N	100	68	88	103	126	140	158	172				
		44 52	32 34	40 46	48 52	60 62	67 70	76 80	81 89				
	16W	108	65	87	104	117	150	143	159				
		55 50	31 33	41 44	50 53	56 58	64 64	70 70	77 80				
	17N	85	46	67	81	101	114	127	139				
		45 33	21 22	29 35	39 39	49 49	56 55	63 61	68 67				
	17W	69	49	72	89	105	121	134	146				
		33 34	22 24	32 37	43 43	51 50	58 59	65 65	72 71				
	18N	63	45	70	89	94	107	127	142				
		30 31	21 22	35 33	44 43	47 47	54 55	63 61	71 68				
	18W	62	48	69	83	97	107	120	133				
		30 29	25 21	37 31	42 39	49 46	53 52	58 59	64 66				
	19N	70	53	75	92	110	126	141	149				
		39 30	28 25	37 36	44 45	54 54	59 64	68 72	71 76				
	19W	66	53	75	87	104	117	132	144				
		33 31	26 25	37 36	43 41	51 51	57 57	66 62	71 68				
	20N	62	49	77	95	119	137	153	173				
		32 28	27 21	40 35	46 46	61 55	70 64	79 71	89 80				
	20W	60	52	81	97	116	135	147	159				
		29 28	28 22	44 45	52 43	60 54	68 63	74 70	79 77				
	21N	93	65	89	101	123	144	161	171				
		48 43	43 28	45 40	51 49	63 57	72 69	81 78	85 85				
	21W	104	63	91	110	124	141	158	173				
		45 53	29 33	41 44	52 58	58 67	67 75	72 83	79 90				
	22N	84	54	77	88	102	113	135	148				
		44 37	30 24	39 35	43 42	51 47	58 55	68 60	76 67				
	22W	80	54	73	86	103	115	127	138				
		42 34	27 24	37 34	42 41	51 48	57 55	61 62	66 67				

Geographic Location	5	50	55	60
Sec.5 Warren Co. Cont'd				
	5			
	44			
	9			
	33			
	2			
	28			
	0			
	28			
	5			
	42			
Sec.4 T22N, R6W Warren Co. Ind.				

Table A.2. (Cont'd.)

Geographic Location	Station No.	Resistance Readings ohm - cm x 100, Depth (Feet): 5	10	15	20	25	30	35	40	45	50	55	60
Sec.5 Warren Co. Cont'd	23N	124 65 60	78 34 42	106 47 55	126 60 65	151 73 73	161 79 78	172 85 85	187 90 91				
	23W	121 56 63	75 35 38	110 51 58	128 61 65	148 72 75	155 77 80	169 83 85	181 88 90				
	24N	89 45 41	56 26 27	69 32 34	71 34 36	73 33 38	76 34 39	84 37 43	85 39 43	85 37 44			
	25N	74 39 33	43 25 17	52 28 23	57 31 24	63 36 27	65 33 29	68 34 30	68 35 30	69 36 33			
	26N	89 36 49	79 38 35	122 58 61	145 75 73	173 84 85	190 86 94	188 94 95	202 95 101				
	26W	94 48 40	82 43 38	116 58 52	139 75 62	172 93 74	195 107 82	209 114 89	221 121 95				
	27N	80 47 30	69 43 25	92 58 39	105 54 47	118 62 55	137 70 63	160 85 71	171 90 78				
	27W	101 64 34	62 33 26	90 47 40	105 55 47	123 65 54	140 74 61	154 81 69	164 89 72				
	28N	87 41 43	48 25 18	55 29 24	74 34 35	80 42 37	85 38 41	95 42 47	100 49 44				
	28W	101 59 39	49 25 18	64 34 28	66 37 26	71 38 28	77 40 33	80 44 36	86 49 37				
	29N	96 40 53	49 20 25	59 24 31	66 31 33	67 30 33	62 27 30	67 32 31	62 30 28	62 30 28			
	29W	125 51 70	47 18 25	56 26 26	52 27 20	59 30 25	53 30 20	57 30 25	58 31 24	60 30 28			
	30N	85 44 39	58 30 25	72 36 35	82 40 37	82 39 42	87 42 42	84 40 42					
	30W	88 46 41	59 32 26	66 34 28	73 40 30	75 43 30	75 44 30	85 46 36	82 45 34				
	31N	142 65 72	82 36 43	99 45 50	96 45 47	97 46 46	90 42 44						
	32N	181 107 76	138 65 67	137 56 76	122 55 60								
	33N	95 54 42	78 39 35	100 56 43	117 60 55	130 68 59	138 71 62	142 75 65	140 72 65				
	33W	93 50 40	71 39 29	102 54 47	114 60 50	114 65 47	126 63 57	133 65 55	148 75 69				
	34N	84 47 33	50 27 17	65 35 25	68 35 27	75 36 34	80 37 38	80 36 40	82 35 42	85 38 42			
	34W	82 46 34	55 31 23	57 33 22	61 32 25	63 34 27	57 30 27	58 30 25					
Sec.4 T22N, R6W Warren Co. Ind.	35N	68 31 34	56 25 29	85 39 43	100 55 52	117 53 62	127 56 67	136 60 71	141 62 75				
	36N	73 34 36	48 21 25	65 30 33	74 36 36	85 41 41	95 47 45	102 50 48	108 53 53				

Geographi Location	45			50		55	60
Sec.4 Warren Co Cont'd							
	49						
		26					
	40			41			
		20	20		21		
	67						
		33					
	89			100			
		31	62		33		
Sec.5 T22N, R6W Warren Co. Ind.							
	165						
		84					
	266			260			
		145	117		137		

Table A.2 . (Cont'd.)

Geographic Location	Station No.	Resistance Readings ohm - cm x 100 Depth (Feet) 5	10	15	20	25	30	35	40	45	50	55	60
Sec.4 Warren Co. Cont'd	37N	73	50	61	70	73	75	77	77				
		36 35	25 24	30 29	36 32	38 33	40 33	41 34	42 33				
	38N	62	40	51	47	49	47	48	50	49			
		29 30	19 20	23 24	23 23	23 23	22 22	22 25	23 25	22 26			
	39N	75	43	46	44	44	44	43	41	40	41		
		34 40	20 23	22 22	21 22	21 22	22 21	22 21	20 20	19 20	20 21		
	40N	146	118	174	201	224	240	237	236				
		73 70	53 62	78 93	90 107	96 125	100 137	97 139	92 142				
	41N	91	55	62	58	58	60	62	63	67			
		47 41	26 26	29 30	26 29	27 30	28 29	29 31	31 31	33 33			
	41W	91	57	57	52	56	64	70	78	89	100		
		40 47	28 25	27 25	24 23	29 24	33 25	39 28	45 29	52 31	62 33		
	42N	58	41	57	62	68	75	82	86				
		28 26	20 17	28 26	29 30	30 33	34 37	37 40	40 42				
	43N	109	82	127	160	189	214	232	240				
		54 51	37 43	56 62	77 77	92 94	106 105	114 112	122 117				
	43W	108	83	121	155	180	206	228	241				
		56 49	40 41	61 59	77 75	91 86	103 99	114 110	122 114				
	44N	210	196	277	314	337	332	327	302				
		100 107	94 98	128 145	148 165	157 174	160 169	160 161	154 144				
	45N	44	48	71	87	101	107	117	120				
		19 19	22 22	35 33	44 39	54 44	58 45	62 51	64 53				
	46W	260	239	339	406	456	491	524	529				
		126 130	109 122	161 174	194 209	220 232	239 249	248 267	247 277				
	47W	325	288	409	505	572	621	704	753				
		147 175	137 153	190 211	236 258	280 290	309 316	337 345	381 365				
	48N	272	264	376	447	532	582	605	645				
		133 132	134 123	194 184	239 204	279 247	300 270	314 292	327 311				
	48W	275	227	350	404	462	548	562	600				
		135 137	111 111	171 178	193 207	217 245	254 293	259 304	272 320				
Sec.5 T22N, R6W Warren Co. Ind.	49N	67	57	97	128	162	197	240	271				
		33 34	27 27	48 45	69 58	85 74	102 90	128 111	145 118				
	50N	119	117	188	229	259	291	306	315				
		55 60	49 67	77 107	95 130	110 146	126 162	132 170	138 172				
	50W	112	112	166	198	235	258	294	318				
		53 53	54 54	79 81	101 93	121 106	138 115	162 126	179 134				
	51N	123	134	202	230	267	299	321	334				
		61 57	67 62	107 92	121 105	138 123	151 142	159 154	164 165				
	51W	107	138	236	268	296	314	332	357				
		51 50	57 78	93 138	108 154	127 165	139 168	149 178	163 189				
	52N	92	60	86	103	124	137	150	153	165			
		50 38	30 29	39 42	50 53	58 60	65 70	73 74	71 77	75 84			
	53N	159	148	213	239	273	285	300	277	266	260		
		82 73	70 73	98 109	110 125	125 142	132 148	133 161	126 145	116 145	117 137		

Geographi Location	5			50			55			60	
Sec.5 Warren Cc Cont'd	1			244			236				
		129	117		122	110		122			
Sec.4 T22N, R6W Warren Co. Ind.	5			45			45			43	
		23	15		24	15		23	14		23
	8			50			42				
		24	24		21	16		21			
	8			40							
		18	18		20						
Sec.17 T22N, R6W Warren Co. Ind.	5										
		29									
	6			59							
		28	28		28						
	8			60			63			66	
		28	28		30	30		31	30		33
Sec.4 T22N, R6W Warren Co. Ind.	2			145			148				
		69	70		71	72		73			
	7			183							
		84	92		87						
	1										
		78									
	2										
		95									
	3			137							
		67	64		69						
	6										
		62									
	3										
		49									
	4										
		68									

Table A.2 . (Cont'd.)

Geographic Location	Station No.	Resistance Readings ohm - cm x 100 / Depth (Feet) 5	10	15	20	25	30	35	40	45	50	55	60
Sec.5 Warren Co.	54N	151	148	190	212	238	255	277	266	261	244	236	
Cont'd		78 76	65 67	93 90	109 100	122 113	129 122	139 133	129 128	129 129	117 122	110 122	
Sec.4 T22N, R6W	55N	62	43	50	47	47	51	49	45	45	45	45	43
Warren		27 28	19 20	21 23	18 23	18 22	19 25	17 24	16 23	16 23	15 24	15 23	14 23
Co. Ind.	55W	70	50	57	61	67	65	65	65	58	50	42	
		32 33	21 24	26 27	27 29	31 31	30 30	33 28	33 28	28 24	24 21	16 21	
	56N	50	34	44	42	41	42	39	38	38	40		
		21 23	16 16	21 21	20 20	20 19	18 21	18 19	17 19	17 18	18 20		
	57W	632	341	285	199	161	134	117	100				
		291 304	152 184	121 160	93 98	85 68	78 49	71 40	61 31				
	58W	237	236	316	324	341	316	304					
		128 104	153 81	211 98	224 94	245 94	231 82	224 73					
	59W	69	38	55	60	67	70	78	80				
		32 34	18 17	26 27	27 31	28 36	28 39	31 44	31 46				
Sec.17 T22N, R6W	60N	58	38	50	54	59	63	66	67				
Warren		29 27	17 18	22 26	24 28	27 30	28 30	31 32	32 32				
Co. Ind.	61N	41	29	42	45	49	55	61	58	65			
		27 22	11 15	16 19	19 25	21 25	25 27	25 30	26 31	29 29			
	62N	39	28	36	41	47	50	53	54	56	59		
		19 17	12 14	17 18	19 20	22 22	23 25	24 26	25 27	26 28	28 28		
	63N	42	27	37	40	45	50	55	56	58	60	63	66
		20 19	12 13	17 18	19 20	22 22	23 25	25 27	26 28	27 28	28 30	30 31	30 33
Sec.4 T22N, R6W	64W	98	67	88	100	126	122	132	138	142	145	148	
Warren		49 46	33 33	43 42	49 49	55 67	59 60	64 64	68 68	69 69	70 71	72 73	
Co. Ind.	65N	110	71	106	118	136	150	159	169	177	183		
		54 53	38 31	54 50	58 57	67 66	75 71	80 78	85 82	90 84	92 87		
	65W	117	72	106	108	120	139	151	152	161			
		56 55	36 34	52 50	52 52	59 58	69 65	77 75	76 73	80 78			
	66W	96	67	106	130	154	166	178	183	192			
		41 52	33 33	52 52	64 64	74 77	80 84	85 88	89 93	92 95			
	67E	77	56	80	88	102	112	121	128	133	137		
		34 42	24 30	37 39	40 46	46 52	52 58	57 62	69 65	62 67	64 69		
	68E	82	51	73	86	98	107	111	115				
		42 37	25 24	36 35	41 42	48 47	51 53	54 55	56 56				
	69E	99	78	96	107	120	128	130	139	136			
		45 50	38 37	47 45	54 50	58 57	64 60	65 61	72 64	69 62			
	70E	81	52	63	76	79	90	95	94				
		36 40	25 26	30 34	36 36	38 41	40 44	43 47	44 46				
	70N	78	50	63	69	77	83	88	95	103			
		39 36	23 25	30 32	33 35	37 37	40 40	44 44	45 47	49 49			
	71N	73	57	78	93	103	111	119	128	134			
		34 36	28 27	37 38	41 49	46 53	51 56	55 60	60 64	63 68			

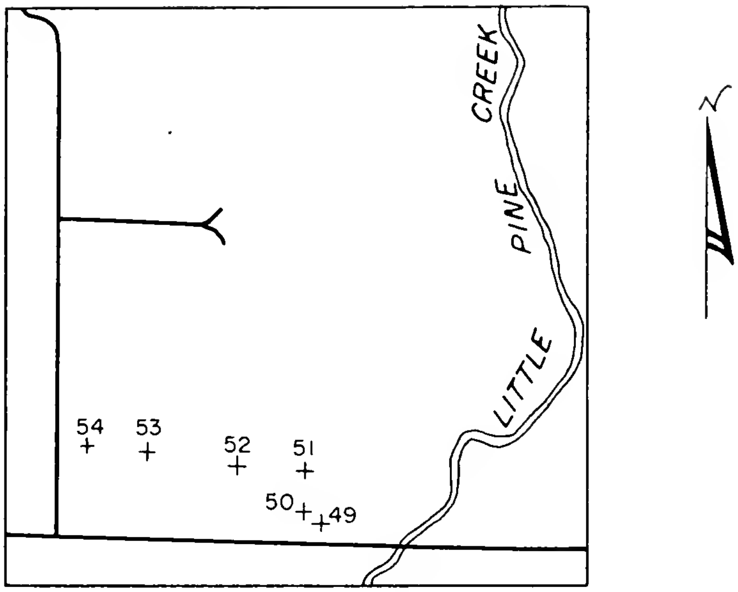
Geographic Location	5	50	55	70
Sec.4 Warren Co. Cont'd	4 72 8 264	540 269 280		
Sec.4 T23N, R5W Tippecanoe Co. Ind.				
Sec.5 T23N, R5W Tippecanoe Co. Ind.				

t resistance readings respectively.

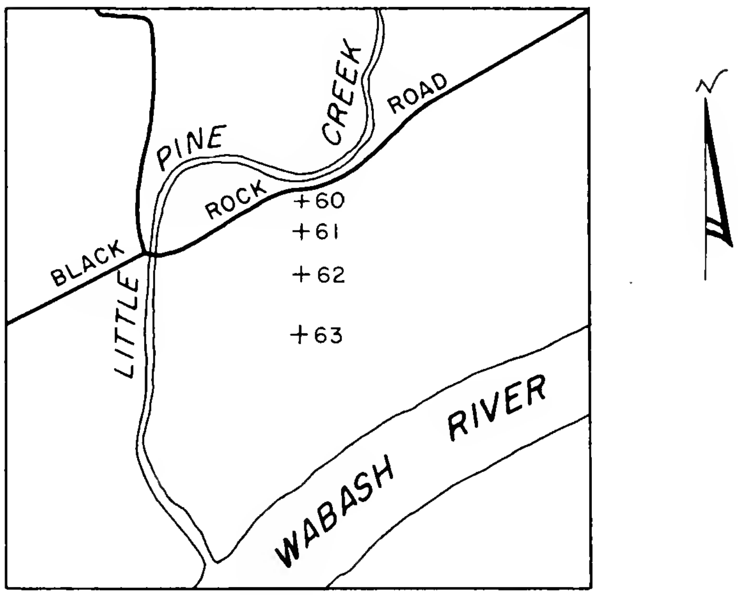
Table A.2. (Cont'd.)

Geographic Location	Station No.	Resistance Readings ohm - cm x 100 — Depth (Feet) 5	10	15	20	25	30	35	40	45	50	55	70
Sec.4 Warren Co. Cont'd	72N	92	78	103	114	128	131	130	127	124			
		42 45	35 40	47 53	52 58	56 70	55 70	55 70	51 71	47 72			
	73N	203	162	256	309	376	423	485	507	528	540		
		97 100	71 84	112 136	142 168	174 193	203 219	229 245	249 258	262 264	269 280		
	74N	130	96	126	151	178	196	215	223				
		62 66	42 50	52 71	64 84	73 101	79 114	83 130	83 137				
	75E	328	310	447	505	601	650	683					
		155 168	157 152	229 215	250 254	295 300	315 332	331 348					
	76N	93	107	154	202	235	257	281	302				
		51 41	59 45	87 64	125 73	156 76	181 73	201 77	221 77				
Sec.4 T23N, R5W Tippecanoe Co. Ind.	77N	150	112	125	113	103	92	83	75				
		73 72	57 51	63 57	59 51	53 44	49 39	45 34	41 32				
	78NW	60	46	48	55	56	57	59	59				
		28 30	20 23	21 25	25 25	26 27	27 27	27 28	28 27				
	79N	169	113	107	82	73	65	56	49				
		74 90	51 57	48 54	38 38	34 34	31 29	26 26	23 22				
Sec.5 T23N, R5W Tippecanoe Co. Ind.	80NNW	263	187	166	147	123	108	84	83				
		126 138	88 98	77 84	66 77	55 63	52 52	38 40	40 40				

a - Letter designates cardinal direction instrument facing.
b - Lee Partion Method used. Upper reading is total resistance and lower readings are left and right resistance readings respectively.



SECTION 5
T 22 N , R 6 W



SECTION 17
T 22 N , R 6 W

FIGURE A.I. LOCATION OF ADDITIONAL RESISTIVITY SURVEY POINTS.

Table A.3 . Soil Moisture Contents*

Site	Sample** Point No.	Date 5-2-66	5-3-66	5-4-66	5-6-66	6-2-66
I	1	--	--	2.8	--	--
		--	--	3.5	--	--
	2	--	--	16.7	--	--
		--	--	15.3	--	--
	3	--	--	10.1	--	--
		--	--	8.5	--	--
	4	--	--	--	--	--
		--	--	8.9	--	--
	5	--	--	8.8	--	--
		--	--	8.2	--	--
	6	--	--	8.9	--	--
		--	--	10.9	--	--
II	7	20.8	--	13.4	--	--
		21.9	--	10.3	--	--
	8	--	--	20.2	--	--
		25.8	--	16.5	--	--
	9	28.4	--	--	--	--
		27.5	--	--	--	--
	10	20.7	--	--	--	--
		19.8	--	--	--	10.0
	11	23.0	--	--	--	--
		29.9	--	--	--	16.6
	12	20.0	--	--	--	--
		20.5	--	--	--	--
	13	--	--	--	--	--
		21.5	--	--	--	--
	14	--	--	--	--	--
		43.0	--	--	--	--
	15	--	--	--	--	--
		21.5	--	--	--	--
	16	15.8	--	10.0	--	--
		15.9	--	7.9	--	--
	17	--	--	14.7	--	--
		--	--	13.8	--	--
	18	--	--	19.7	--	--
		--	--	16.4	--	--
	19	--	--	14.6	--	--
		--	--	17.0	--	--
	20	--	--	25.8	--	--
		--	--	16.5	--	--
	21	--	--	20.6	--	--
		--	--	18.4	--	--
	22	--	--	12.5	--	--
		--	--	13.8	--	--

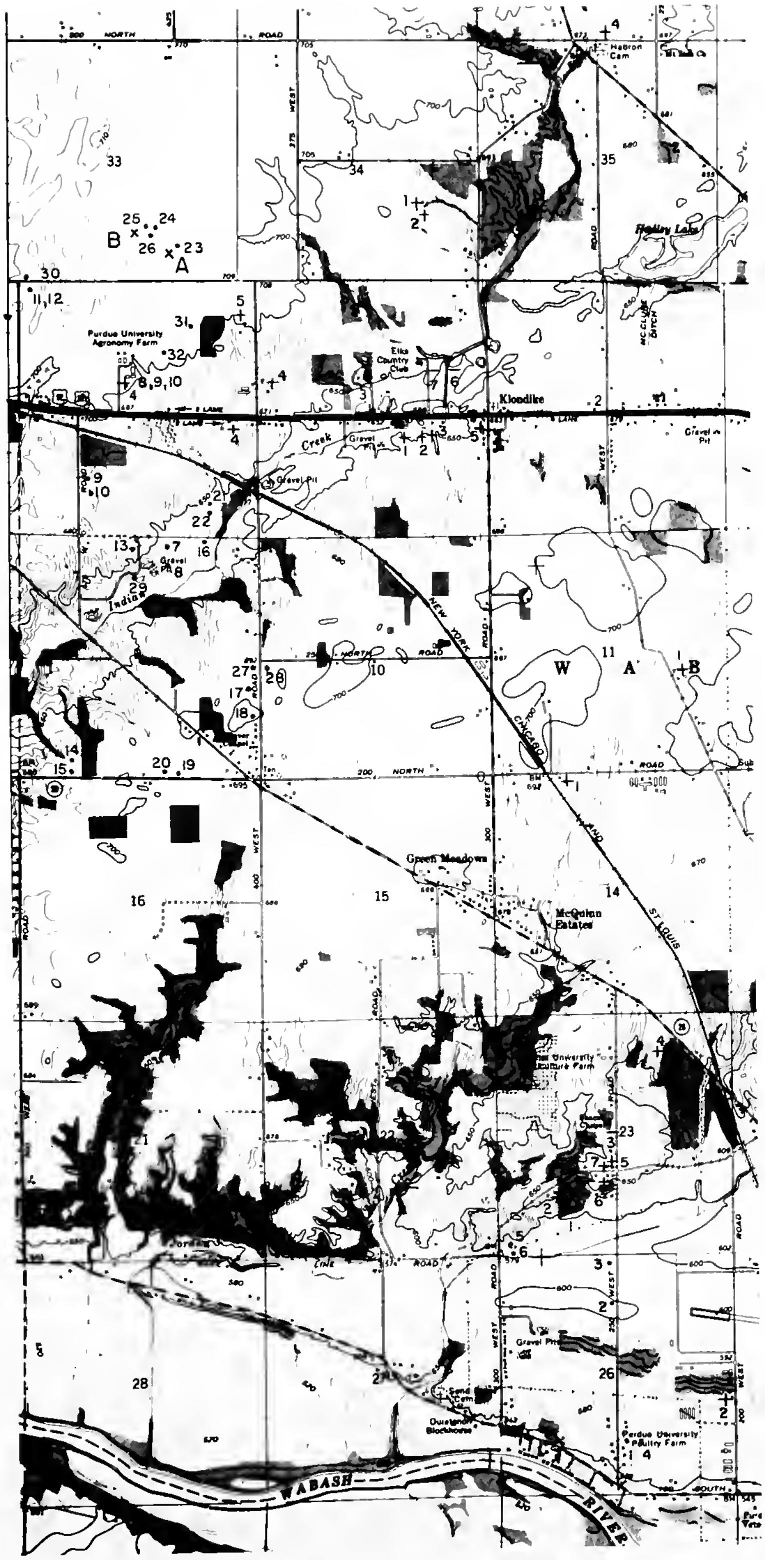
* Samples for measurement taken from top 6 inches of surface.
** Refer to Figure A.2, A.3 for location of Sampling Sites.

Table A.3. (Cont'd.)

Site	Sample Point No.	Date				
		5-2-66	5-3-66	5-4-66	5-6-66	6-2-66
II	23	--	--	--	3.2	--
		--	--	--	17.1	--
	24	--	--	--	15.2	--
		--	--	--	13.2	--
	25	--	--	--	15.0	--
		--	--	--	18.3	--
	26	--	--	--	25.9	--
		--	--	--	26.3	--
	27	--	--	--	--	--
		--	--	--	--	19.3
	28	--	--	--	--	--
		--	--	--	--	20.7
	29	--	--	--	--	--
		--	--	--	--	3.5
	30	--	--	--	--	--
		--	--	--	--	12.9
	31	--	--	--	--	--
		--	--	--	--	22.1
	32	--	--	--	--	--
		--	--	--	--	11.9
III	33	--	14.4	--	--	--
		--	20.5	--	--	11.3
	34	--	18.5	--	--	--
		--	18.9	--	--	13.3
	35	--	--	--	--	14.0
		--	--	--	--	14.5
	36	--	--	--	--	12.8
		--	--	--	--	10.4
	37	--	26.9	--	12.4	--
		--	18.1	--	13.0	14.9
	38	--	13.9	--	--	--
		--	16.7	--	--	11.8
	39	--	--	7.9	--	--
		--	--	9.6	--	--
	40	--	21.4	--	--	--
		--	20.0	--	--	--
	41	--	23.2	--	--	--
		--	24.7	--	17.3	--
	42	--	23.2	--	--	--
		--	23.7	--	15.1	--
	43	--	23.5	--	--	--
		--	22.6	--	11.8	--
	44	--	21.3	--	--	--
		--	20.2	--	9.2	--
	45	--	29.2	--	--	--
		--	26.9	--	--	--

Table A.3 . (Cont'd.)

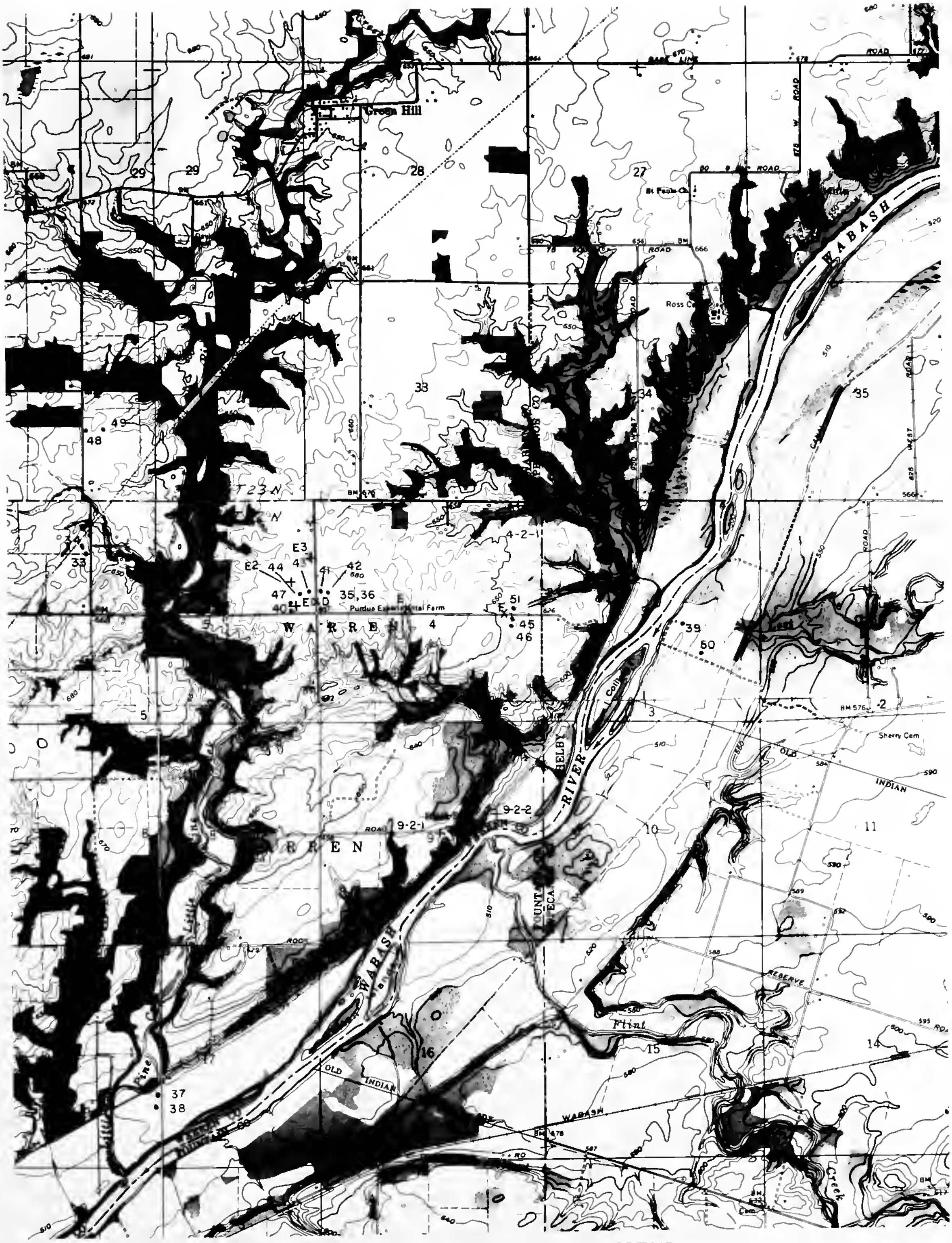
Site	Sample Point No.	Date				
		5-2-66	5-3-66	5-4-66	5-6-66	6-2-66
III	46	--	23.5	--	20.1	--
		--	18.2	--	18.9	--
	47	--	22.5	--	--	--
		--	22.5	--	--	--
	48	--	23.0	--	--	--
		--	24.1	--	--	--
	49	--	24.0	--	--	--
		--	24.1	--	--	--
	50	--	--	11.3	--	--
		--	--	13.4	--	--
	51	--	--	--	22.1	--
		--	--	--	18.3	--



LEGEND

- • SITE OF SOIL MOISTURE
- + BORINGS AND WELL LOGS
- × RADIOMETER SITES

FIGURE A.2 LOCATION OF FIELD TEST SITES AND EXISTING BORINGS AND WELLS – SITES I & II.



LEGEND

× RADIOMETER SITES · SITE OF SOIL MOISTURE

\+ BORINGS AND WELL LOGS

FIGURE A.3 LOCATION OF FIELD TEST SITES AND EXISTING BORINGS AND WELLS — SITE III.

Table A.4. Meteorological Data, Agronomy Farm for One Week Prior to Flights

Date	Temperature (°F) max.	Temperature (°F) min.	Precipitation (in.)	Wind[a] (miles/day)	Evaporation[b]
May 7 '65	72	59	0.17	66	0.07
May 8 '65	81	59	0.00	91	0.25
May 9 '65	83	65	0.00	97	0.27
May 10 '65	80	61	0.00	110	0.21
May 11 '65	74	44	0.00	95	0.22
May 12 '65	72	52	0.00	77	0.25
May 13 '65	80	46	0.00	101	0.34
June 25 '65	78	48	0.00	87	0.33
June 26 '65	80	53	0.00	79	0.35
June 27 '65	86	61	0.00	83	0.32
June 28 '65	90	70	0.00	159	0.36
June 29 '65	89	66	0.89	108	0.53
June 30 '65	83	61	0.03	64	0.17
July 1 '65	77	49	0.00	87	0.19
July 20 '65	80	57	0.00	58	0.26
July 21 '65	77	60	0.00	58	0.26
July 22 '65	79	61	0.00	62	0.15
July 23 '65	92	69	0.00	53	0.21
July 24 '65	93	73	0.00	33	0.25
July 25 '65	93	59	0.00	55	0.28
July 26 '65	83	55	0.00	31	0.23
Aug. 26 '65	85	61	0.51	87	0.31
Aug. 27 '65	85	61	0.74	103	0.34
Aug. 28 '65	85	51	0.00	96	0.23
Aug. 29 '65	65	35	0.00	86	0.22
Aug. 30 '65	69	48	T[c]	34	0.11
Aug. 31 '65	77	56	0.72	80	0.09
Sept. 1 '65	71	58	0.51	41	0.07
Sept. 8 '65	83	64	0.00	23	0.14
Sept. 9 '65	81	67	T	26	0.09
Sept. 10 '65	87	69	0.00	84	0.22
Sept. 11 '65	82	54	0.00	111	0.22
Sept. 12 '65	62	58	0.00	118	0.06
Sept. 13 '65	77	63	0.00	50	0.12
Sept. 14 '65	82	64	0.00	31	0.16
Oct. 1 '65	68	49	1.10	103	0.03
Oct. 2 '65	57	43	0.00	54	0.07
Oct. 3 '65	70	42	0.00	63	0.14
Oct. 4 '65	60	32	0.00	74	0.16
Oct. 5 '65	56	31	0.00	30	0.09
Oct. 6 '65	59	37	0.00	48	0.12
Oct. 7 '65	71	47	0.15	58	0.10

Table A.4 . (Cont'd.)

Date	Temperature (°F) max.	min.	Precipitation (in.)	Wind[a] (miles/day)	Evaporation[b]
Oct. 19 '65	81	48	0.00	69	0.16
Oct. 20 '65	75	52	0.38	54	0.08
Oct. 21 '65	68	53	0.00	38	0.05
Oct. 22 '65	61	48	0.44	82	0.09
Oct. 23 '65	51	41	0.05	69	0.00
Oct. 24 '65	53	32	0.00	173	0.14
Oct. 25 '65	48	31	0.00	72	0.04
Oct. 26 '65	62	35	0.00	73	0.14
Apr. 25 '66	67	44	0.00	70	0.12
Apr. 26 '66	70	47	0.55	31	0.19
Apr. 27 '66	72	40	0.00	156	0.26
Apr. 28 '66	60	40	0.17	118	0
Apr. 29 '66	58	43	0.00	110	0.17
Apr. 30 '66	64	41	0.54	132	0.21
May 1 '66	63	35	0.11	116	0.11
May 2 '66	53	29	0.00	148	0.15
May 3 '66	58	33	0.00	62	0.14
May 4 '66	57	32	0.00	73	0.22
May 5 '66	61	36	0.00	124	0.25
May 6 '66	80	55	0.00	215	0.39
May 26 '66	76	52	0.00	46	0.21
May 27 '66	82	58	0.00	45	0.24
May 28 '66	87	52	0.00	81	0.34
May 29 '66	75	37	0.00	111	0.31
May 30 '66	65	39	0.00	76	0.22
May 31 '66	65	40	0.00	88	0.25
June 1 '66	65	39	0.00	92	0.29
June 2 '66	69	40	0.00	39	0.22

a. Anemometer is 18 inches above grass.
b. Daily evaporation in inches from a tank 4 feet in diameter.
c. T-less than .005 inch.

Table A.5. Hourly Meteorologic Data, Purdue Airport, May 6, 1966

Time (L.S.T.)	Temperature (°F)	Dewpoint (°F)	Station Pressure (in.)	Wind Direction (00-36)	Wind Speed (KTS)	Total Sky Cover
0058	67	55		29	12	0
0158	65	58		27	12	0
0258	64	54	29.330	30	10	0
0351	61	51		30	08	0
0458	61	44		31	10	0
0558	60	44	29.400	30	10	0
0657	61	41		33	10	0
0757	64	35		33	15	0
0857	67	31	29.405	36	15	0
0957	68	29		03	14	0
1057	67	28		02	15	0
1157	71	31	29.485	35	12	0
1258	71	31		02	12	0
1358	71	31		36	106.19	0
1471	72	31	29.430	32	07	0
1556	72	32		32	07	0
1656	72	37		34	08	0
1758	69	35	29.410	32	07	0
1857	64	35		05	06	0
1970	61	35		06	06	0
2059	59	35	29.435	07	05	0
2158	54	35		10	04	0
2257	51	37		00	00	0
2358	64	35	29.430	00	00	8

Summary: 24 hr. precip. 0; max. temp. 72°F; min. temp. 51°F.

Table A.6. Hourly Meteorologic Data, Purdue Airport, June 1, 1966

Time (L.S.T.)	Temperature (°F)	Dewpoint (°F)	Station Pressure (in.)	Wind Direction (00-36)	Wind Speed (KTS)	Total Sky Cover
0058	42	36		00	00	0
0158	39	36		00	00	0
0258	40	36	29.485	00	00	0
0358	38	36		00	00	0
0458	38	36		00	00	0
0558	43	42	29.515	00	00	0
0656	51	42		00	00	0
0757	56	40		04	05	0
0856	61	36	29.535	09	09	0
0957	65	37		04	12	1
1057	65	35		05	08	3
1157	65	34	29.520	02	07	3
1254	68	32		00	00	1
1356	70	31		07	08	0
1456	67	30	29.480	00	00	0
1556	69	33		00	00	0
1656	69	33		00	00	0
1756	68	35	29.470	09	06	0
1856	65	37		09	05	0
1956	54	43		36	08	0
2058	56	37	29.515	03	07	0
2156	53	37		03	05	0
2256	51	36		05	06	0
2358	49	36	29.535	00	00	0

Summary: 24 hr. precip. 0; max. temp. 70°F; min. temp. 38°F.

Table A.7 . Hourly Meteorologic Data, Purdue Airport, June 2, 1966

Time (L.S.T.)	Temperature (°F)	Dewpoint (°F)	Station Pressure (in.)	Wind Direction (00-36)	Wind Speed (KTS)	Total Sky Cover
0058	47	37		00	00	0
0158	44	38		00	00	0
0258	40	37	29.525	00	00	0
0351	40	38		00	00	0
0458	41	39		00	00	0
0558	47	43	29.555	00	00	0
0658	53	44		00	00	4
0758	64	43		21	06	3
0858	68	42	29.560	21	10	2
0956	71	39		20	09	6
1057	72	37		21	06	6
1157	74	41	29.540	22	10	7
1257	75	39		22	08	7
1357	76	38		24	07	10
1458	77	38	29.475	24	05	10
1558	77	43		23	10	10
1658	77	40		19	07	7
1758	76	40	29.445	16	08	7
1856	69	42		18	07	7
1956	65	42		18	06	8
2058	64	42	29.475	19	04	10
2156	62	41		17	04	10
2256	61	43		00	00	10
2356	61	44	29.475	00	00	10

Summary: 24 hr. precip. 0; max. temp. 77°F; min. temp. 40°F.

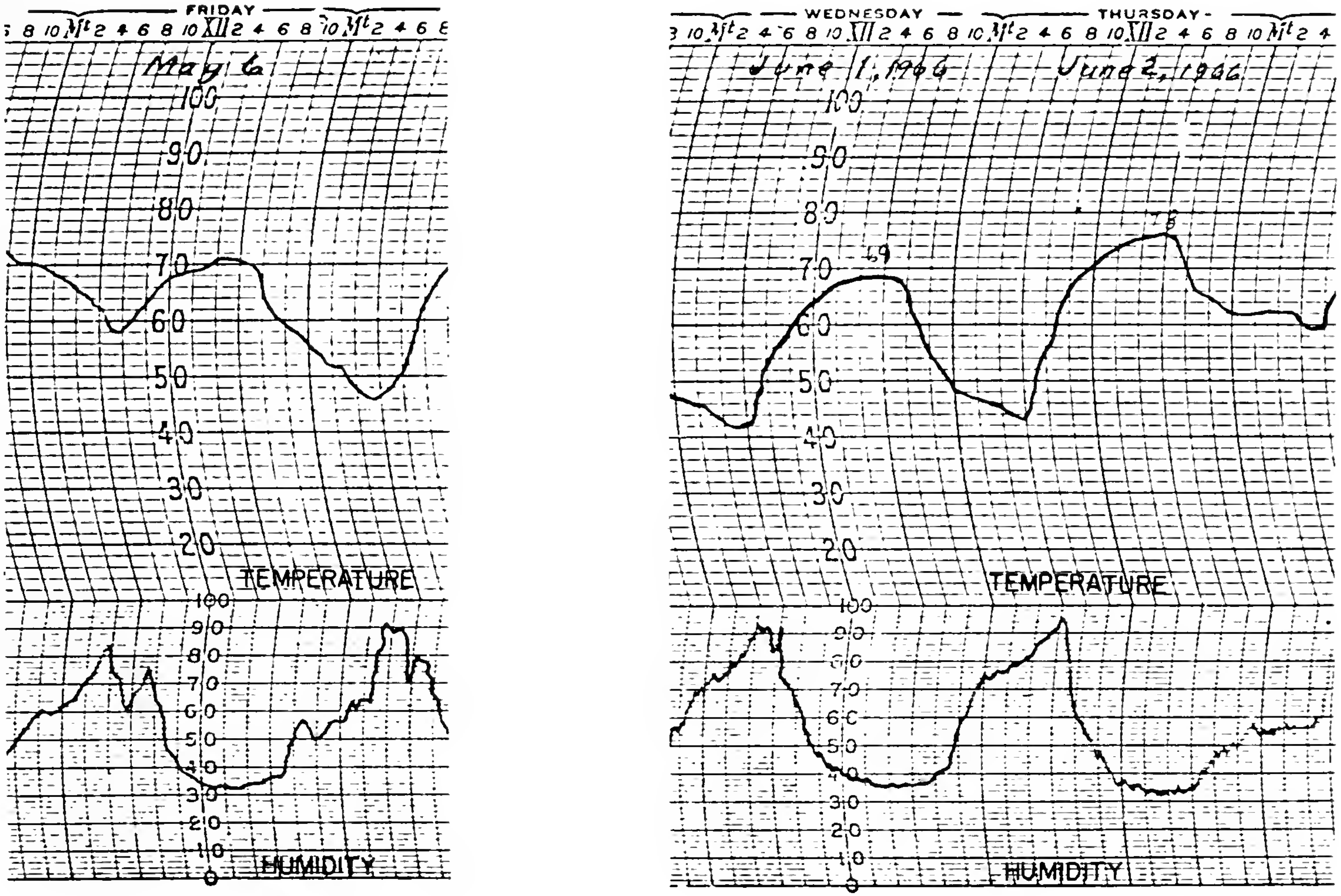


FIGURE A.4 HYDRO-THERMOGRAPH, AGRONOMY FARM.

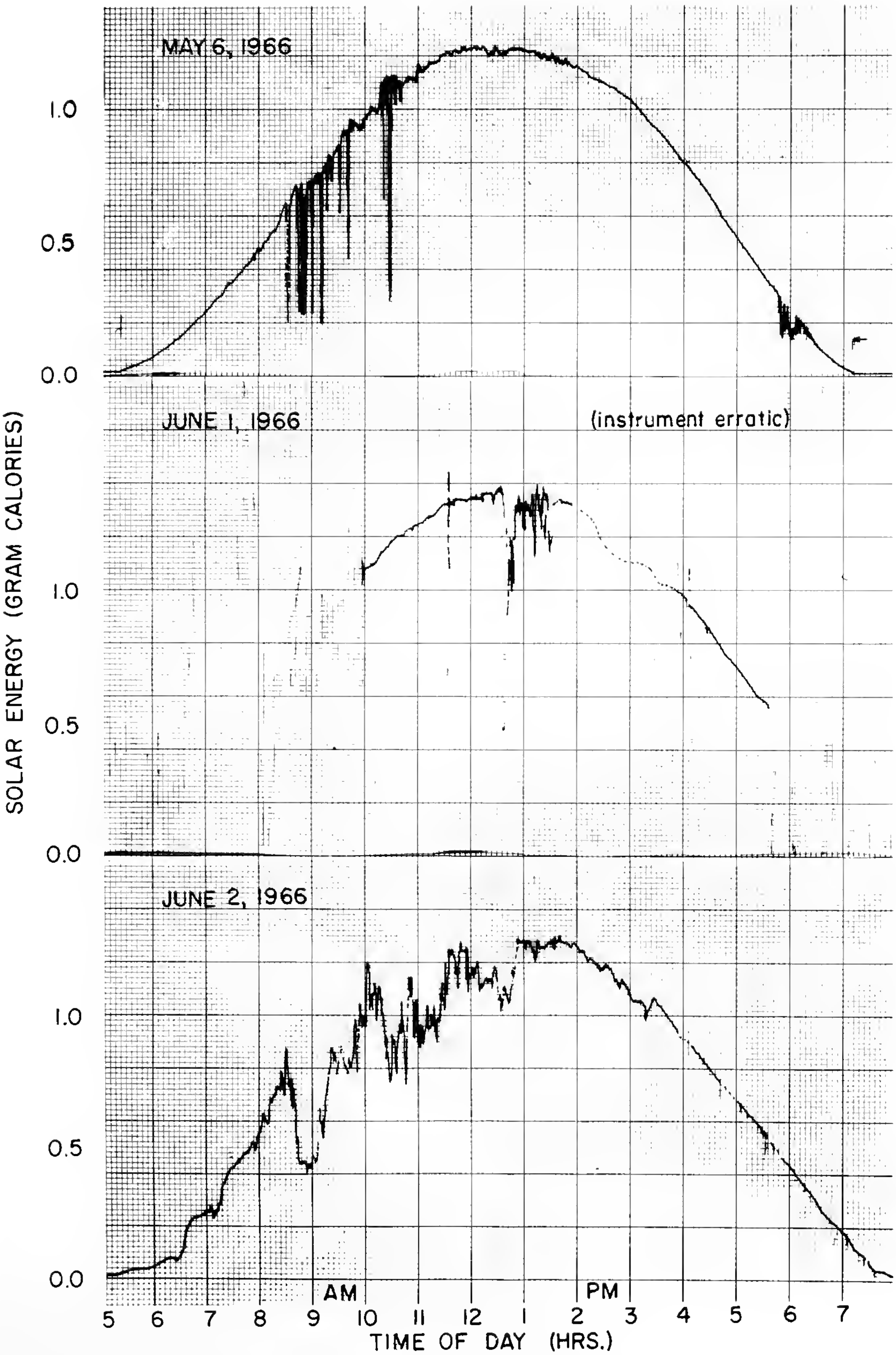


FIGURE A.5 SOLAR ENERGY RECORDING, AGRONOMY FARM.

Table A.8. Well Logs Sites I & II (152)

TcB 26-4
Altitude: 692 SW¼ SW¼ SE¼ SEC. 26

	Thickness (feet)	Depth (feet)
Fill	3	3
Hardpan, yellow	7	10
Clay, blue	18	28
Clay, blue, with sand streaks	40	68
Gravel, yellow, dry	12	80
Clay, gritty, blue	8	88
Hardpan, gritty	3	91
Sand, yellow, and gravel; dry	19	110
Sand, yellow, and gravel; water-bearing	14	124
Sand, coarse, gray, and coarse gray gravel; water-bearing	5	129
Sand, coarse, and some gravel at		129

TcB 34-1
Altitude: 692 SW¼ NE¼ SE¼ SEC. 34

	Thickness (feet)	Depth (feet)
Drift	90	90
Shale	80	170

TcB 34-2
Altitude: 692 SW¼ NE¼ SE¼ SEC. 34

	Thickness (feet)	Depth (feet)
Drift	30	30
Gravel	10	40

TcE 34-1
Altitude: 664 NE¼ NE¼ SEC. 34

	Thickness (feet)	Depth (feet)
Soil, clay	10	10
Clay, gritty, hard	17	27
Gravel, medium	2	29
Clay, gritty, hard	73	102
Clay, sandy, hard	34	136
Clay, gravelly	7	143
Lime rock (boulder)	1	144
Clay, sandy, hard	24	168
Sand, muddy	7	175
Clay, sandy, hard	17	192
Sand, coarse, and gravel; water-bearing	4	196
Sand, coarse, water-bearing	4	200
Sand, coarse, and gravel, clean; water-bearing	10	210
Gravel, medium, clean, water-bearing	15	225

TcF 3-1
Altitude: 650 NW¼ SE¼ SEC. 3

	Thickness (feet)	Depth (feet)
Top soil	6	6
Gravel	51	57

TcF 3-2
Altitude: 650 NW¼ SE¼ SEC. 3

	Thickness (feet)	Depth (feet)
Top soil	6	6
Gravel	16	22

TcF 3-3
Altitude: 653 NW¼ SE¼ SEC. 3

	Thickness (feet)	Depth (feet)
Top soil	6	6
Gravel	54	60

TcF 3-4
Altitude: 680 W½ SW¼ NW¼ SEC.3

	Thickness (feet)	Depth (feet)
Drift	72	72
Gravel, coarse, blue, water-bearing	13	85

TcF 3-5
Altitude: 655 NE¼ NE¼ SE¼ SEC. 3

	Thickness (feet)	Depth (feet)
Clay, yellow	12	12
Gravel, dry	26	38
Clay, blue	20	58
Hardpan, blue, with sand streaks	2	60
Gravel, dry	20	80
Clay, blue, with sand and gravel streaks	15	95
Sand, muddy	3	98
Clay	2	100
Sand, muddy	2	102
Sand and gravel; fair	1	103
Clay, with gravel streaks	20	123
Sand and gravel, coarse; water-bearing	5	128
Still in good gravel at		128

TcF 3-6
Altitude: 650 SE¼ NE¼ SEC.3

	Thickness (feet)	Depth (feet)
Soil	2	2
Clay, gritty, yellow	10	12
Hardpan, gritty, brown	6	18
Gravel, dry	7	25
Hardpan, blue	8	33
Shale, blue	120	153
Shale, blue, hard	16	169
Limestone, hard, blue	3	172
Limestone, gray	8	180
Shale, brown	11	191

TcF 3-7
Altitude: 650 SE¼ NE¼ SEC. 3

	Thickness (feet)	Depth (feet)
Soil, black	2	2
Clay, gritty, brown	12	14
Sand, yellow, and some gravel	15	29
Gravel, coarse, and sand	6	35
Sand	2	37
Gravel, small, and sand	3	40
Clay, blue, at		40

TcF 4-4
Altitude: 680 NE¼ SE¼ SEC.4

	Thickness (feet)	Depth (feet)
Drift	30	30
Limestone	20	50

Table A.8. (Cont'd.)

TcF 4-5
Altitude: 700 NE $\frac{1}{4}$ NE $\frac{1}{4}$ NE $\frac{1}{4}$ SEC. 4

	Thickness (feet)	Depth (feet)
Drift	95	95
Limestone, hard (water-bearing at 500')	880	975
Shale, soft	25	1000

TcF 4-8
Altitude: 705 NE $\frac{1}{4}$ SE $\frac{1}{4}$ SW $\frac{1}{4}$ SEC. 4

	Thickness (feet)	Depth (feet)
Clay, sand, and some gravel	28	28
Clay, gray-brown, hard, and gravel	27	56
Sand, fine gravel; water-bearing	6	62
Shale, light gray	8	70

TcF 4-9
Altitude: 705 SE $\frac{1}{4}$ NW $\frac{1}{4}$ SEC. 4

	Thickness (feet)	Depth (feet)
Clay, sand, and a little fine gravel; light brown formation	20	20
Same as above with more gravel	6	26
Gravel, packed, dirty, water-bearing	4	30
Clay, sand, and gravel	18	48
Shale, hard, light gray	2	50
Shale, light to dark gray, water-bearing (little)	20	70

TcF 4-10
Altitude: 705 SE $\frac{1}{4}$ NW $\frac{1}{4}$ SEC. 4

	Thickness (feet)	Depth (feet)
Clay, sand, and gravel	24	24
Clay, sand, and more gravel	36	60
Shale, light gray	30	90
Shale, dark gray, at		90

TcF 11-1
Altitude: 695 SE $\frac{1}{4}$ NW $\frac{1}{4}$ SEC. 4

	Thickness (feet)	Depth (feet)
Soil	1	1
Clay, yellow	11	12
Clay, blue	43	55
Hardpan, blue	3	58
Clay, blue, with sand streaks	7	65
Clay, blue	20	85
Gravel, dry	33	118
Clay, blue	5	123
Gravel, dry	52	175
Sand, fine, yellow, water-bearing	5	180
Sand, water-bearing	9	189
Sand and some gravel	1	190
Gravel, coarse, and sand	3	193
Sand, coarse, and some gravel	4	197
Gravel, coarse	4	201

TcF 14-1
Altitude: 690 NW $\frac{1}{4}$ NE $\frac{1}{4}$ NW $\frac{1}{4}$ SEC. 14

	Thickness (feet)	Depth (feet)
Fill	3	3
Clay	15	18
Clay, sandy, blue	72	90
Clay, sandy, brown	20	110
Quicksand	15	125
Sand, gray, some gravel, chunks of wood	4	129
Clay, gritty, brown	24	153
Sand, gray, water-bearing	15	168
Gravel, coarse, gray, water-bearing	6	174
Still in gravel at		174

TcF 26-2
Altitude: 580 NE $\frac{1}{4}$ NE $\frac{1}{4}$ SE $\frac{1}{4}$ SEC. 26

	Thickness (feet)	Depth (feet)
Soil	1	1
Clay, sandy, yellow	11	12
Gravel, dry	47	59
Clay, blue	26	85
Gravel, muddy	1	86
Clay, blue	62	148
Clay, sandy, blue	1	149
Gravel, muddy, and sand; water-bearing	4	153
Sand and gravel; water-bearing	6	159
Sand at		159

Table A.9. Well Logs Sites I & II (Additional Data)

Sites I & II		
Tippecanoe - $SW\frac{1}{4}$ $NE\frac{1}{4}$ $SW\frac{1}{4}$ Sec. 23 (F23-1) Altitude 655	Thickness (feet)	Depth (feet)
Black soil	2	2
Yellow clay	10	12
Gray sandy hard clay	20	32
Dry yellow sand and gravel	16	48
Gray sandy hard pan	22	70
Dry yellow sand and gravel	3	73
Gray hard pan	50	123
Dry gravel	13	136
Water bearing sand and gravel	12	148
Tippecanoe - $SW\frac{1}{4}$ $NE\frac{1}{4}$ $SW\frac{1}{4}$ Sec. 23 (F23-2) Altitude 655		
Clay	38	38
Dry gravel	18	56
Clay	5	61
Dry gravel	6	67
Clay	4	71
Dry gravel	2	73
Clay	47	120
Gravel	20	140
Clay	20	160
Gravel	6	166
Tippecanoe - $SE\frac{1}{4}$ $SE\frac{1}{4}$ $NW\frac{1}{4}$ Sec. 23 (F23-3) Altitude 655		
Yellow clay	20	20
Blue clay	20	40
Dry sand and gravel	60	100
Dirty dry sand	30	130
Dry sand and gravel	20	150
Gray sand and gravel	45	195

Table A.9. (Cont'd.)

Sites I & II (Cont'd.)		
Tippecanoe - $SE\frac{1}{4}$ $NW\frac{1}{4}$ $NE\frac{1}{4}$ Sec. 23 (F23-4) Altitude 675	Thickness (feet)	Depth (feet)
Top soil and brown clay	20	20
Gray clay	80	100
Dry brown sand	48	148
Water bearing brown sand	22	170
Water bearing brown gravel	4	174
Tippecanoe - $NE\frac{1}{4}$ $NE\frac{1}{4}$ $SW\frac{1}{4}$ Sec. 23 (F23-5) Altitude 655		
Yellow clay	15	15
Blue clay	20	35
Sand and gravel	10	45
Blue clay	90	135
Yellow clay	25	160
Cemented yellow sand	20	180
Cemented gray sand	20	200
Cemented coarse sand and fine gravel	15	215
Tippecanoe - $SE\frac{1}{4}$ $NE\frac{1}{4}$ $SW\frac{1}{4}$ Sec. 23 (F23-6) Altitude 660		
Yellow clay	16	16
Gravel	2	18
Blue clay	29	47
Yellow clay	8	55
Dry gravel and sand	56	111
Gray clay	21	132
Dry gravel	6	138
Water bearing sand	4	142
Gray and yellow water bearing sand and some gravel	9	151
Coarse and small water bearing gravel and sand	7	158
Same with more sand		158+

Table A.9. (Cont'd.)

Sites I & II (Cont'd.)		
Tippecanoe - SE$\frac{1}{4}$ NE$\frac{1}{4}$ SW$\frac{1}{4}$ Sec. 23 (F23-7) Altitude 660	Thickness (feet)	Depth (feet)
Clay	6	6
Dry gravel	14	20
Blue clay	26	46
Dry gravel	54	100
Brown sandy clay	20	120
Blue clay	20	140
Water bearing gravel	17	157

Table A.10. Well Logs and Borings Site III

Site III		
E-1 SE¼ NE¼ SE¼ Sec. 5 Warren Co. Altitude 685	Thickness (feet)	Depth (feet)
Top soil	2	2
Light brown clayey silty sand	10	12
Yellow silty sand	4	16
Cherty yellow sandstone	14	30
E-2 SE¼ NE¼ SE¼ Sec. 5 Warren Co. Altitude 685		
Top soil	2	2
Yellow brown clayey sand	13	15
Cherty yellow sandstone	10	25
E-3 NE¼ NE¼ SE¼ Sec. 5 Warren Co. Altitude 684		
Top soil	5	5
Sand and gravel	10	15
Cherty yellow sandstone		15+
4-2-1 NE¼ NE¼ NE¼ Sec. 4 Warren Co. Altitude $\underline{\Omega}$ 620		
Topsoil and brown clay	12	12
Gray clay	19	31
Hard rock	2	33
Sandstone	20	53
Warren Co. Sec. 9 T22N, R6W (9-2-1) (starts at 21 feet)		
Blue hard shale	21	45
Shale, gray	15	60
Blue shale	40	100
Sandy shale, gray	10	110
Black shale	20	130
Lime ledge	4	134
Shale (sandy) gray	57	191

Table A.10. (Cont'd.)

Site III (Cont'd.)		
Warren Co. Sec. 9 T22N, R6W (9-2-2)	Thickness (feet)	Depth (feet)
Top soil	1	1
Yellow clay	15	16
Blue clay, soft	38	54
Blue clay and streaks of brown sand	7	61
Gray sand	14	75
Coarse gravel and sand	1	76
Clay	12	88
Blue hard shale	15	103
Soft blue shale	1	104

APPENDIX B

APPENDIX B

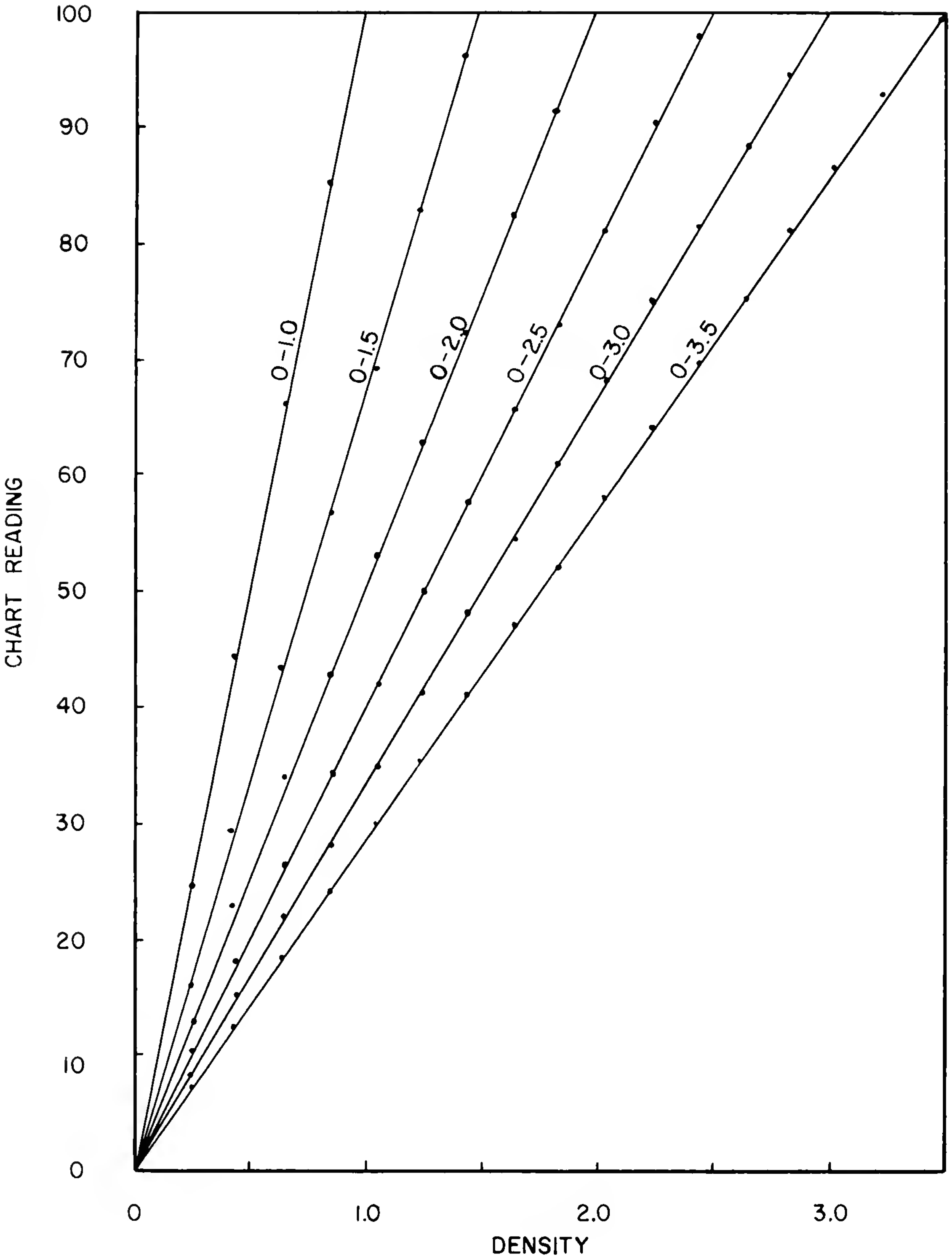


FIGURE B.1 CALIBRATION CHART FOR TRANSMISSION DENSITOMETER (TD-102).

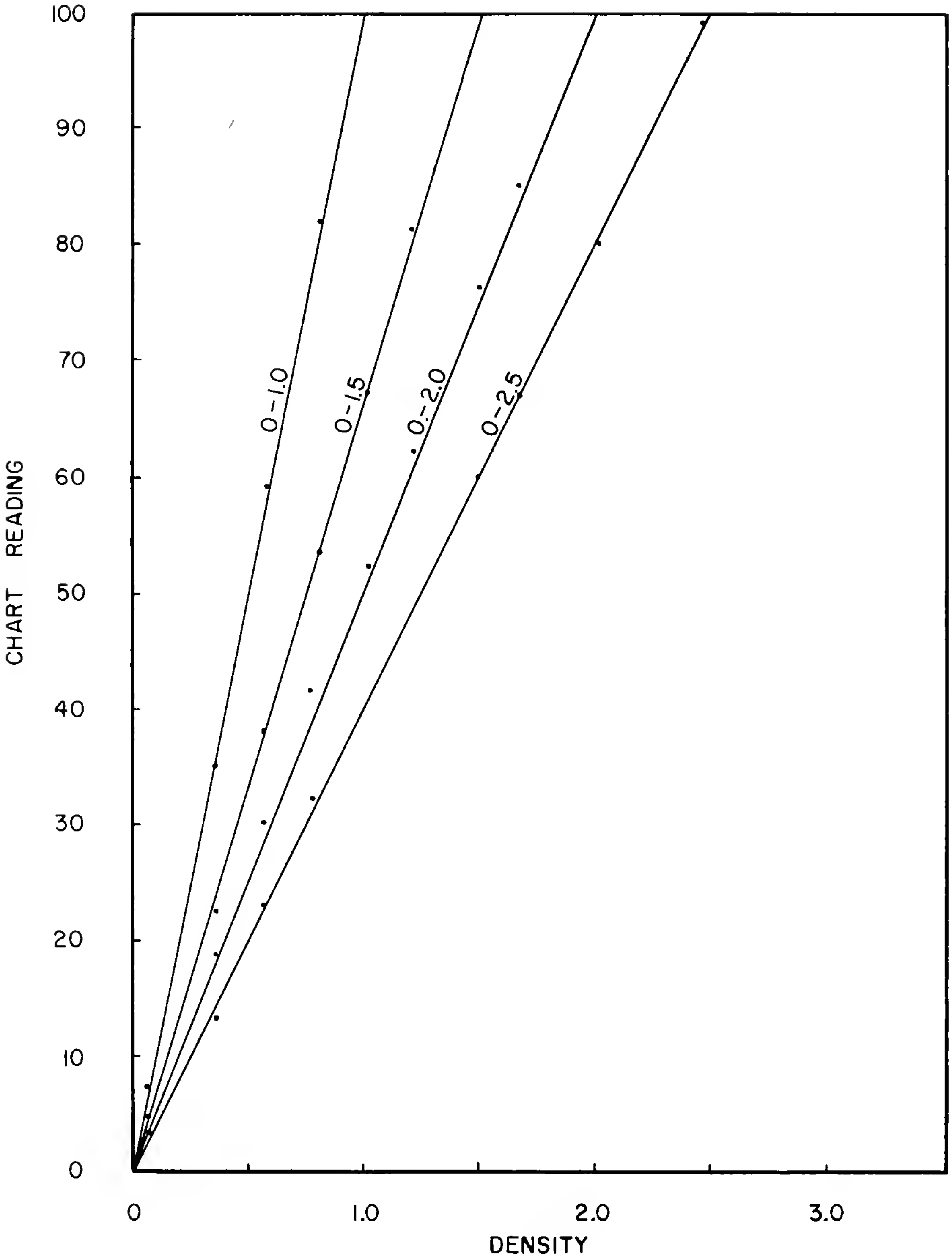


FIGURE B.2 CALIBRATION CHART FOR REFLECTION DENSITOMETER (RD-100).

VITA

VITA

Harold T. Rib was born January 9, 1931 in New York City, New York. He obtained his elementary and high school education in the public schools of New York City, and his Bachelor of Civil Engineering degree from the City College of New York in February 1953.

Mr. Rib worked for the U.S. Army Corps of Engineers, New York District as a soils engineer from February 1953 to April 1954 and again from May 1956 to September 1956. From April 1954 to April 1956 Mr. Rib was in the U.S. Army where he served as an instructor in the Signal School at Fort Monmouth.

He entered Cornell University in September 1956 where he majored in Aerial Photographic Interpretation. He received his Master of Science degree in June 1957.

From June 1957 to April 1958 he worked for Keystone Mapping Company in Arlington Virginia where he was head of the Photographic Interpretation Section. In June of 1958 he joined the staff of the Materials Division of the Bureau of Public Roads as a Highway Research Engineer.

Mr. Rib entered Purdue University in September 1964 and his schooling until June 1965 was under the auspices of the Bureau of Public Roads. He obtained a leave of absence from the Bureau to complete his requirements for a Ph.D. degree at Purdue.

Mr. Rib is a member of Tau Beta Pi, Chi Epsilon, Sigma Xi, and the American Society of Photogrammetry. He is Chairman of Subcommittee IV -

Engineering Uses of the Photo Interpretation Committee of the American Society of Photogrammetry and is a member of the Aerial Surveys and Photogrammetry Committee of the Highway Research Board.

Mr. Rib is a citizen of the United States, is married and is the father of three children.